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Research on Gasification of Wood In a Plasma Pyrolysis Unit

by

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Tearsheet Annotation

The report provides results, observations and conclusions obtained through experimental research on biomass gasification in a Plasma Pyrolysis Unit.

ABSTRACT

The report provides a quick summary of the properties of wood waste and its value as an energy source. Various gasification techniques are discussed and compared before the actual experimental work is presented.

The experiments are carried out in a plasma research facility and, although not completely conclusive, they have proven that very good quality gas can be produced. Minor equipment addition to the existing set-up should enable production of better quality gas and higher gas yields as well as minimization of electricity consumption.

Plasma gasification, due to its simple, versatile controls and capability of producing a good quality gas, has proven itself as a very promising new gasification technology deserving of an opportunity for further research and development.

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1.0 INTRODUCTION

Wood is a renewable resource, the technology for utilizing its energy is available, pollutant emissions are controllable, net energy balances are favourable, the cost is competitive in many areas, and with proper forest management there is potentially a net benefit to the forest ecosystem. In comparison with other fuels, wood can be a useful alternative.

Solid waste from wood-fuelled plants can be landfilled or lagooned in an acceptable manner. It is possible for the ash to be returned to the forest to return some of the nutrients and to act as a soil conditioner.

Gasification is a process which converts a solid fuel into easily handled fuel gases. Wood gasification has traditionally been used to produce a clean fuel suitable for lighting, heating and shaft power applications when mere convenient hydrocarbon fuels were unavailable. Representative configurations are the so-called fixed (both counter-current and co-current gas-solid flows), the moving, the suspended, and the fluidized bed reactors.

The upgrading of wood residues to produce a clean gaseous fuel has been used several times in recent technological history. It is evident that interest in wood gasification is high as a result of the recognition that non-renewable resources are finite. The combination of increasing fuel demand and difficulties in securing supplies implies that alternative fuel substitutions will take place in the near and medium future.

There is reason to believe that gasification using plasma arc torches is a competitive technology in that total gasification is achievable with little or no ash residues. The process is easily monitored and controlled as will be

explained later.

Over the past 18 months Resorption Canada Limited (RCL) has conducted laboratory tests to demonstrate the technical feasibility of wood gasification using plasma arc torches in a plasma processing facility. This process will be referred to as the "Reductagas" process.

The properties of wood and its potential for gasification was investigated under contract with Supply and Services Canada (SSC). Conventional technologies were studied in order to gain knowledge of conditions that should be used and of problems encountered so as to refrain from using conditions that have previously been proven to be ineffective.

The first few experiments conducted can be classified as preliminary in that they supplied valuable information which enabled rapid optimization for the remainder of the experiments.

2.0 PROPERTIES OF WOOD

2.1 General: The chief constituents of dry wood are cellulose, lignin, hemicelluloses, extractives and various ash-forming minerals. The major constituent is cellulose, approximately 50% by weight. Lignin is next, 23-33% in softwoods and 16-25% in hardwoods.

2.2 Thermal Properties

Thermal Conductivity is strongly dependent on the wood's moisture content, the type and amount of extractives present, density, grain direction and several structural defects.

$k = 1.39\ Sg + CPm + 0.165$ (approximate)

Where k = thermal conductivity, in./hr.sq ft.degree F.

Sg = specific gravity at specified moisture content.

Pm = moisture content, %(0-1.0)

C = constant whose values are 0.028 for Pm 40% and 0.038 for Pm 40%.

Table 1 gives the thermal conductivity and density for different woods.

Table 1: Thermal Conductivity Data For Different Woods (k values based on O.D. wood and traverse to grain;85 deg F temp)(from ref 1)

Wood Type	Weight Density (lb/cu ft)	Thermal Conductivity (BTU,in./hr.sq ft.deg F.)
Balsa	10	0.41
Spruce	21	0.62
Basswood	24	0.69
Aspen	26	0.71
Pine,white	25	0.72
Pine,southern	35	0.94
Maple,sugar	43	1.13
Elm,rock	48	1.16

Specific Heat is the ratio of the media's heat capacity compared to that of water.

For oven dry wood: $Cp' = 0.25 + 0.006T$

Where Cp' = specific heat of oven dry wood, Btu/lb.mole deg F.

T = temperature, deg F

For wet wood: $Cp = \frac{X + Cp'}{1 + X} + Phi$

Where Cp = specific heat of moist wood, BTU/lb.mole deg F

X = fractional moisture content

Phi= moisture content constant,which is a function of temp.

Thermal Diffussivity is a measure of the media's ability to absorb heat from the surroundings.

$Et = k/dCp$

Where E is in sq in/sec and d is the density in lb/cu ft. Thermal diffussivity for wood is small compared to other materiels. The typical value is 0.00025 sq in/sec.

2.3 Heating Value: On an oven dry basis the heating values of different wood species do not vary greatly, being approximately 8280 BTU/lb. Resin on the other hand has a heating value of approximately 17,000 BTU/lb. Therefore, wood species containing significant portions of resin have markedly higher heating values. Examples of resin-rich species are pine, spruce, larch and douglas fir. In general, bark tends to have a slightly higher heating value than wood, although it depends on the wood species. Table 2 gives typical heating values for wood and bark for various wood species.

Table 2: Average Heating Values of Wood and Bark (from ref 1)

Wood Species	Heating Value (BTU/lb,O.D.) Bark	Wood	Wood Species	Heating Value (BTU/lb,O.D.) Bark	Wood
Balsam Fir	8950	8150	Red Alder	8410	7990
Beech	NA	8150	Red Maple	NA(a)	7990
Black Cottonwood	9000	8800	Red Oak	8080	8050
Black Willow	7250	NA	Southern Pine	9360	8600
Douglas Fir	9790	8890	Sugar Maple	7370	NA
Eastern Hemlock	8870	8410	Sweetgum	7530	NA
Elm	NA	8170	Sycamore	NA	7990
Englemann Spruce	8420	NA	Western Hemlock	9400	8410
Hickory	NA	8050	Western Red Cedar	8790	9700
Lodgepole Pine	10,260	NA	Western Larch	8280	NA
Paper Birch	9490	NA	White Fir	NA	8210
Ponderosa Pine	NA	9110	White Oak	7070	8150
Quaking Aspen	8500	NA	Yellow Birch	9140	NA

a. Not Available

2.4 Elemental and Ultimate Analysis: This describes the wood's composition. It is worth noting that, unlike most fossil fuels, wood and bark contain no sulphur which eliminates SO2 emmission problems. Also most woods and barks have low ash contents compared to coal. Coal generally yields an ash content in the range of 5-25% whereas the ash content of wood is less than 1% for most species. Table 3 gives the elemental analysis of oven dry hogged wood fuel and bark for various wood species.

Table 3: Elemental Analysis of Oven Dry Hogged Wood Fuel and Bark (from ref 1)

Wood Species	Percent of Dry Fuel Weight					
	Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur	Ash
			Wood			
California Redwood	5.9	53.5	0.1	40.3	N(a)	0.2
Western Hemlock	5.8	50.4	0.1	41.4	0.1	2.2
Douglas Fir	6.3	52.3	0.1	40.5	N	0.8
Pine(sawdust)	6.3	51.8	0.1	41.3	N	0.5
			Bark			
Western Hemlock	6.2	53.0	0.0	39.3	N	1.5
Douglas Fir	5.8	51.2	0.1	39.2	N	3.7
Loblolly Pine	5.6	56.3	-	37.7	N	0.4
Longleaf Pine	5.5	56.4	-	37.4	N	0.7
Shortleaf Pine	5.6	57.2	0.4	36.1	N	0.7
Slash Pine	5.4	56.2	0.4	37.3	N	0.7

a. Negligible amounts

2.5 Proximate Analysis: This gives the ratio of volatile matter, fixed carbon and ash content in the wood. Fixed carbon is the residue remaining after the extraction of volatiles and ash so it is not the same as elemental carbon. The volatile matter in wood is approximately 85% of dry wood weight. Table 4 gives the proximate analysis of wood and bark for various wood species. The moisture content has a large effect on the heat recoverable from wood fuel. The vapourization of water to steam requires 970 BTU/lb and additional heat is required to raise the temperature to flue levels, 390-450 deg F. Table 5 illustrates the combustion efficiency and moisture content for several wood species.

Table 4: Proximate Analysis of Oven-Dry Wood and Oven-Dry Bark (from ref 1)

Wood Species	Percentage of dry fuel weight Volatiles	Fixed Carbon	Ash
		Wood	
Western Hemlock	84.8	15.0	0.2
Douglas Fir	86.2	13.7	0.1
White Fir	84.4	15.1	0.5
Ponderosa Pine	87.0	12.8	0.2
Redwood	83.5	16.1	0.4
Cedar	77.0	21.0	2.0
		Bark	
Western Hemlock	74.3	24.0	1.7
Douglas Fir(old growth)	70.6	27.2	2.2
(young growth)	73.0	25.8	1.2
White Fir	73.4	24.0	2.6
Ponderosa Pine	73.4	25.9	0.7
Red Alder	74.3	23.3	2.4
Redwood	71.3	27.9	0.8
Cedar	86.7	13.1	0.2
Loblolly Pine	65.7	33.9	0.4
Slash Pine	65.9	33.4	0.7

Table 5: Variation of Combustion Efficiency With Moisture Content (from ref 1)

Wood Species	Moisture Content Gr Wood	Heating Value BTU/lb	Reco'ble Heat,Dry BTU/lb	Reco'ble Heat,Wet BTU/lb	Efficiency % Dry	Moist
Loblolly Pine	50	8600	7230	6020	84	70
Beech	35	8150	6800	6120	83	75
Elm	46	8170	6780	5800	83	71
Red Maple	42	7990	6630	5750	83	72
White Oak	40	8150	6800	5950	83	66
Sycamore	53	7990	6630	5270	83	66
Hickory	39	8050	6680	5950	83	74

3.0 GASIFICATION TECHNOLOGIES

3.1 General

The potential value of the colossal amounts of the cellulose wastes and forest product residues as renewable sources of fuel and energy is enormous. On a weight per weight basis, the average heat value of natural fuels (4500 cal/gm) is not too far below the average heat values for different types of coal, which range from 7915 cal/gm for lignite. The comparison becomes more favourable by pyrolysis of natural fuels which could provide charcoal and various chemicals from the char and volatile factions. Lack of sulphur in wood is favourable to wood gasification.

The new scientific information and technology could be applied to the gasification of wood to provide a number of products and by-products, ranging from solid, liquid and gaseous fuel to activated charcoal and polyfunctional compounds as a substitute for the petrochemicals.

Product gas generated is useful both as a fuel and a chemical raw materiel. Related R&D has been on coal and municipal solid waste (MSW). Both technologies appear readily transferable to wood biomass feedstccks. The product gas is the initial step in the manufacture of substitute natural gas, ammonia and methane.

The various gasification systems designed for wood, wood residue and municipal refuse high in cellulose content are being designed to operate under atmospheric pressure. Coal gasification can operate at pressures in excess of 400 psig. Atmospheric gasifiers yield a crude gas composed of hydrogen, carbon monoxide, carbon dioxide, nitrogen and small amounts of methane and heavy hydrocarbons. Roughly 2% of the wood on a dry basis is converted to an oil-tar.

Partial oxidation can be run either with air or oxygen. When the oxidation step is run with air, the crude gas generated consists of roughly 42% nitrogen with a heating value of around 180 BTU/scf. When oxygen is used, the nitrogen dilution is eliminated and the heating value increases to around 350 BTU/scf. In both cases, a high moisture content is associated with the synthesis gas. The excess moisture must be removed from the gas, which is an additional and significant cost to the process.

Tests have shown that the presence of water in the feed makes energy recovery very inefficient, eg. compare one tonne feeds of 7.3 and 43.3% moisture producing 18,470 cu ft of gas containing 545 BTU/cu ft and 17,741 cu ft of gas containing 447 BTU/cu ft respectively. The energy available in the total gas produced declined by 21% due to the presence of the additional 36% moisture.

The problem of moisture in wood waste can be minimized by dilution or solved by predrying. Mixing wood waste and MSW appears to offer the advantage of alleviating problems for both feedstocks. MSW contains 24% inorganic materiel; this could be diluted reducing certain efficiency, erosion, and pollution problems associated with it as an energy source. Wood waste contains large volumes of water, which could be reduced by blending the feedstock with the inherently drier MSW. Thus the problems inherent with individual feedstocks can be minimized, if not solved, by the process of blending.

When dissimilar organic waste streams are mixed, direct combustion may not be an ideal approach to energy production, because blending introduces additional heterogeneity into the feed materiel. Conversion of the feedstock to a uniform fuel solves that problem, ie. gasification and then combustion.

3.2 Pyrolysis-Gasification Chemical Reactions

Pyrolysis is defined as the "destructive distillation of organic material heated to 600 deg C without the addition of Oxygen".

When wood is heated in the absence of oxygen, a sequence of reactions takes place, the relative proportions of which depend on the rate of heating. On heating wood slowly:

(1) Around 100 deg C there is a loss of water;
(2) From 100 deg C to 250 deg C the wood loses mainly CO2 and water;
(3) From 250 deg C to 500 deg C a fairly rapid de-volatilization of gases and tars takes place; and
(4) What is left is a solid char composed mainly of carbon.

Complete gasification occurs as the products of pyrolysis are heated from 600 deg C to around 1000 deg C. Vapours and gaseous compounds undergo further fragmentation and react with the remaining carbonaceous residues. Virtually the only products then remaining are carbon monoxide, water vapour, carbon dioxide, hydrogen, methane, and an inorganic ash. The relative proportions of each gas are determined through altering the ultimate reaction temperature, the mode of heating, the gases used for heating, and the moisture content and composition of the feedstock. The heating value of the gas will range from 100 to 400 BTU/cu ft.

It has been shown that moisture was the principal parameter affecting gas composition. At moisture contents of 35 to 55% wood left an ash of 0.3%. As temperatures approached 1000 deg C the gaseous products were very similar; wood, MSW, etc. Cracking of complex organic vapours as well as gasification of carbonaceous residues approached completion. The resultant gaseous products were essentially reduced to simple mixtures of H2, CO, CO2, H2O, CH4 and where sulphur was

present, H_2S. Trace amounts of ethane and ethylene were sometimes found. When the water content was drastically reduced the ultimate gas products were the same but in different molar concentrations.

Three important reactions in gasification are:

$$C + H_2O \rightleftharpoons CO + H_2$$

$$C + CO_2 \rightleftharpoons 2CO$$

$$C + 2H_2 \rightleftharpoons CH_4$$

Once formed the relative molar composition of the products formed in the above reactions are governed by reactions including:

$$C + 2H_2O \rightleftharpoons CO_2 + 2H_2$$

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

Equilibrium conditions will be approached only in those reactions which occur rapidly. Clearly, kinetics may play a controlling role in determining the composition of gaseous products formed in the reactor operating under steady state conditions. Reactor designs can be modified, within limits, to favour formation and isolation of desired products that can be controlled by kinetics.

It is frequently stated that a pyrolysis procedure cannot compete with direct combustion procedures in efficient recovery of energy. A complete comparison must be made including economics, safety, environmental impact and other considerations.

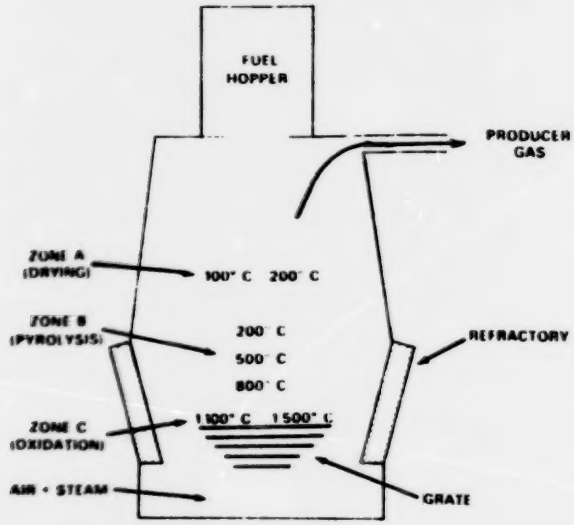
Pyrolysis-gasification provides a fuel gas that can be stored, transported, and processed. The system can be used in parallel with other energy producing systems.

3.3 Gasifier Configurations

Fixed Bed Up-Draught Gasifier

In most gasification systems the pyrolysis processes are heated by the oxidative combustion of the char in situ. They all require external heat sources such as a means of combusting one of the non-gaseous products, the char or the oil, and transferring this heat to the pyrolysis reactor. The majority of the systems available today are autogenous with the char oxidation and pyrolysis taking place in the same reactor. The archetypical gas producer which has been sold in the thousands since the early 1900s is the so-called Fixed Bed Up-Draught unit (see Figure 1).

Figure 1: The Fixed Bed Up-Draught Gasifier (from ref 3).



In zone A: Drying at 100-200 deg C

$$\text{Wet Wood} + \text{Heat} \rightleftharpoons \text{Dry Wood} + \text{Steam}$$

In zone B: Pyrolysis at 200-500 deg C

$$\text{Dry Wood} + \text{Heat} \rightleftharpoons \text{Char} + CO + CO_2 + H_2O + CH_4 + C_2H_4 + \text{Pyroligneous Acids} + \text{Tar}$$

In zone C: Oxidation of char at 1100-1500 deg C

Char + O2 + H2O(Steam or moisture) $\rightleftharpoons$ CO + H2 + CO2 + Heat

Reaction	Thermochemistry at 500 deg C H° KJ/mole	
1. C + O2 $\rightleftharpoons$ CO2	-394	Exothermic
2. C + CO2 $\rightleftharpoons$ 2CO (Boudouard reaction)	+172	Endothermic
3. H2O + CO $\rightleftharpoons$ CO2 + H2(Water gas shift)	+2.85	Endothermic
4. H2O + C $\rightleftharpoons$ CO H2	+175	Endothermic
5. C + 2H2 $\rightleftharpoons$ CH4	-75	Exothermic

The first two processes are driven by the heat given out in the oxidation zone.

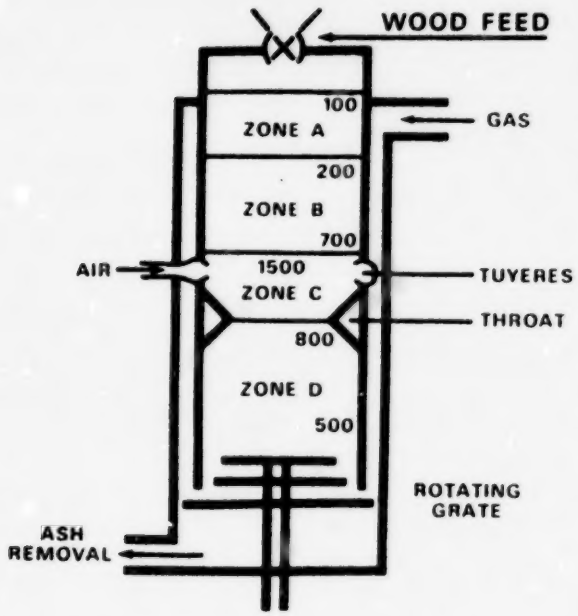
Reaction 1 is the sole source of heat to drive the process and explains why the efficiency of gasification will not exceed about 70%, cold gas basis, since some part of the fuel input is required to maintain the high temperatures of the pyrolysis zone. Steam is utilized to regulate the bed temperature and to improve the product gas.

Reaction 5 is not favoured at high temperatures and low pressures.

The Down Draught Gasifier

The Down Draught gasifier is designed so that the tars and other gases all have to pass through the hot oxidation Zone C (see Figure 2). The gases produced by the combustion and "cracking" of the tars are then passed along with solid carbon into the reaction Zone D. This zone serves to reduce carbon dioxide and water vapour to carbon monoxide and hydrogen by means of the reactions 2 and 4 above.

Figure 2: The Down Draught Gasifier (from ref 3).



Zone D is the Reduction Zone. Ideally all of the oxygen from both the wood and the air is in the form of carbon dioxide and water after passing through Zone C so that the reactions are:

$H2O + Char \rightleftharpoons CO + H2$; and

$CO + Char \rightleftharpoons 2CO$

These reactions are endothermic and eventually they cool the charcoal and ash to below 600 deg C and the reaction then almost ceases so that the reduction "freezes" at the final gas composition. The reduction zone places two significant restrictions on the wood fuel composition. Firstly, the fuel should carbonize to a fairly strong structure with a fairly large particle size so that the gases will flow easily through the reduction zone. Secondly, because of the heat removal effects of water vapour both by chemical reactions 3 and 4 as well as the physical evaporation of water in Zone A there is a limit to the water content of the feedstock to around 25%.

The Fluidized Bed Gasifier

The fluid bed consists of an inert mass of a powdered materiel such as sand which is suspended by a fast flow of gas up through it. At the appropriate flowrate the individual particles are separated from one another and the whole bed appears as though it is boiling with large turbulent currents moving the sand particles around very rapidly. If other substances are introduced into the fluid bed they will, depending on their density and size, appear to float or sink but at the same time they will be in contact with many sand particles. Fluidized Bed gasifiers use sand and char as the fluid medium and can be air or oxygen blown. The wood is admitted either onto or under the surface of the bed. The reactions described above take place at the surface of the particle which is heated very rapidly by the hot sand particles. The result is that there is a very rapid pyrolysis of the wood and the product gas contains high concentrations of methane and other small pyrolysis product hydrocarbons. The heat is supplied by the oxidation of the char and at any moment the bed will contain only a small portion of fuel. The time taken by a piece of wood to be completely converted to gas is very short, of the order of minutes, compared with the hours taken in other gasifiers.

3.4 Specific Gasifier Systems

The Occidental Flash Pyrolysis Process

Feed materiel would be mixed with recycled solids from a char burner at a ratio of the order of five lbs of char to every 1b of wood and carried into a vertical transport reactor by recycled gas. Rapid mixing occurs in the reactor as the materiel in suspension passes upward under turbulent conditions allowing high heat transfer rates within the mixture during a relatively short residence time. This minimizes further thermal degradation of materiels and should maximize liquid product yields. Materiels consisting of char, oil and gas leave the pyrolysis reactor at around 950 deg F

and pass through a cyclone separator to remove the char.

Moore-Canada System

This system consists of a moving bed reactor. The oxidizing medium consists of air and steam so a relatively high nitrogen content arises in the raw gas resulting in a low heating value fuel.

In this system the biomass enters through the top of the reactor. Non-combustible materiels are discharged from the reactor's bottom. The maximum temperature that can be attained, with oxygen combustion, is 2200 deg F in the lower zone of the reactor. The waste materiel is discharged as an ash and is solid and granular in nature. Crude gas exits the reactor at approximately 160-180 deg F. Steam is also fed in with the air as it tends to increase the hydrogen content in the product gases.

Purox Process

This process was developed by the Union Carbide Corporation specifically for the partial oxidation of municipal solid waste. The oxidizing medium used is oxygen. The process utilizes a moving bed through which oxygen is passed countercurrently to the downward flowing feed stream. As the waste materiel flows through the reactor it passes through successive stages of drying, reduction and oxidation. At the bottom of the reactor ash is removed in a molten state at temperatures in excess of 3000 deg F. The crude gas, which contains a large percentage of moisture, exits at the top of the reactor at a temperature of around 200 deg F.

Batelle Pacific Northwestern Laboratories

A study was conducted on the partial oxidation of municipal refuse in a pilot plant. The study was extended to cover the partial oxidation of wood chips with air and steam as the oxidizing medium. The system consisted of a three foot

diameter Moving Bed reactor. Results obtained were similar to the Moore-Canada pilot studies.

Alberta Industrial Development Limited

A demonstration plant for the gasification of wood residues, thermex system, was constructed. The system yields a char and low BTU gas. The gasifier consists of a Fluidized Bed type reactor that uses waste wood fuel particles less than two inches in size.

British Columbia Research Council

A Cross Flow reactor is one in which air is admitted opposite to the gas exit with the fuel admitted from either the top or the side. The reactions taking place are similar to those in the Down Draught reactor. The British Columbia Research Council has developed a Co-Current reactor which is partially fluidized using the ash and char as the fluidizing medium. Unlike the true fluidized bed this reactor has quite large temperature and concentration gradients but still produces a good fuel gas with a reduced tar concentration though enriched in methane and it has the high throughput characteristics of the fluid bed.

On a very large scale the Koppers-Totzek reactor, reference 5, is an example of an Entrained Flow Co-Current reactor in which pulverized fuel such as wood is blown along with air through a large reaction chamber in which combustion and then reduction takes place to produce a gas composed only of hydrogen and carbon monoxide as fuel components.

3.5 Summary of Conventional Gasifiers

Figure 3 is a summary of the different gasifier reactor types and their performance variables. From the reaction temperature plots it can be seen that the Up-Draught unit has excellent heat transfer characteristics from the gas stream to the descending fuel. All of the other configurations will

require some form of heat recovery from the leaving gas for efficient performance in applications other than the direct use of the dirty gas.

Figure 3: Performance Summary of Gasifiers (from ref 3)

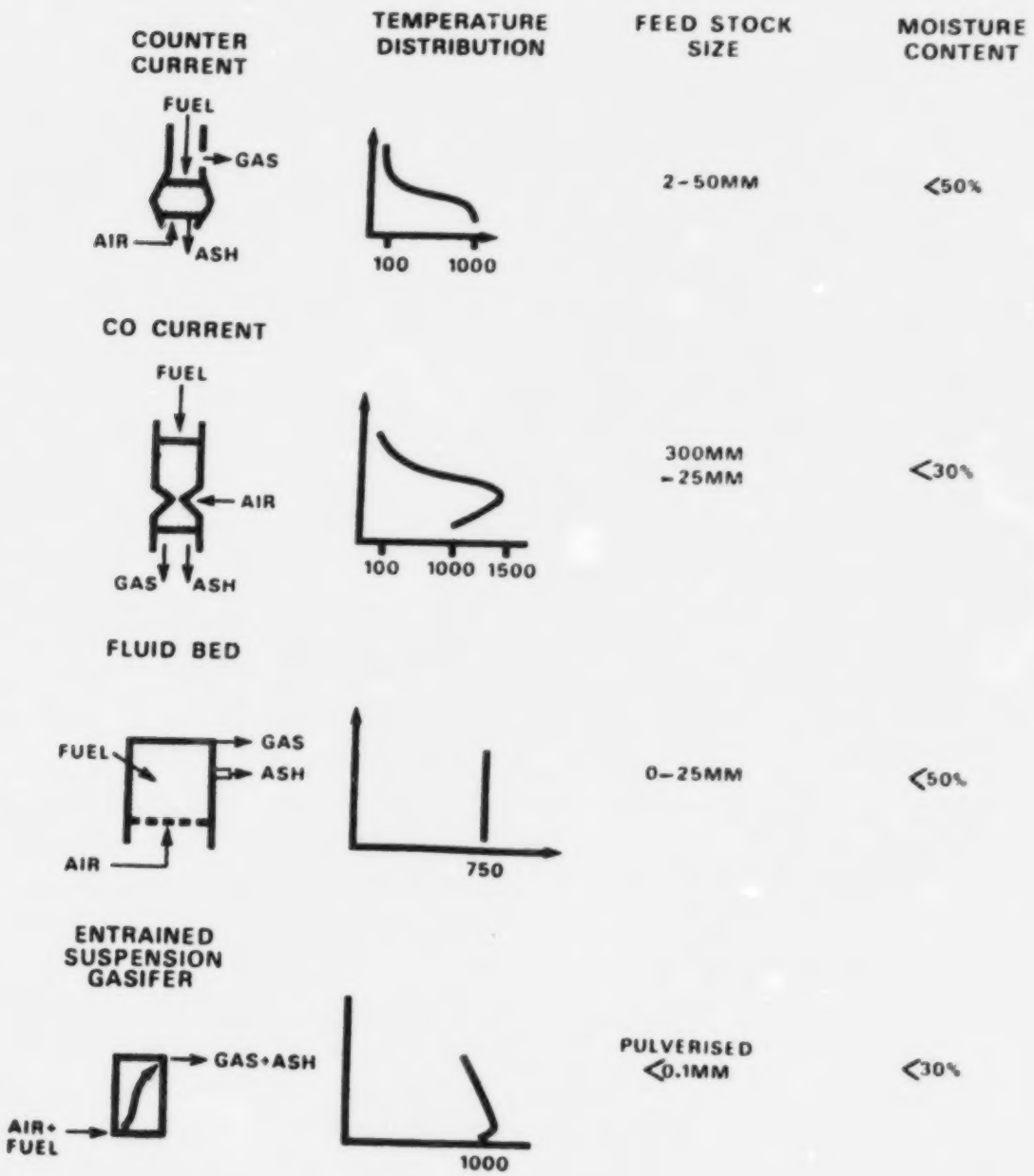


Table 6 is a sample of the gas analyses of the different gasifier types. In general the nitrogen content is around 50% with carbon dioxide in the range 10-15% and the remainder comprises the fuel gases on a dry gas basis. The higher heating value of the gas mixtures has been calculated from the heats of combustion of each component which are provided in Table 7.

Table 6: Producer Gases From Wood (from ref 3)

Gasifier Type	Gas Analysis (Oxygen and Moisture Free) CO2	N2	CO	H2	CH4	Unsaturates	Heat Content (BTU/cu.ft)
Up-Draught							
Suction Gas	13.7	52.1	17.4	9.8	4.6	2.4	167
Westwood Polygas	11.5	47.0	22.0	16.0	2.5	1.0	156
Down Draught							
Imbert	11.2	49.3	20.5	17.0	2.0	-	134
Fouchet	16.0	46.8	13.3	21.0	2.6	0.3	133
Duvant	15	48	15	20	2	-	125
Fluid Bed							
BC Research	11.2	53.3	15.8	13.1	3.7	1.6	150
Eco Research	16.52	44.7	14.8	16.9	5.7	1.4	174

Table 7: Higher Heat of Combustion of Gases Produced in Wood Gasification

	BTU/SCF
Carbon Monoxide CO	316.0
Hydrogen H2	287.5
Methane CH4	994.7
Ethane C2H46	1742.6
Ethylene C2H4	1585.3

3.6 Gasifier Construction & Auxilliary Equipment

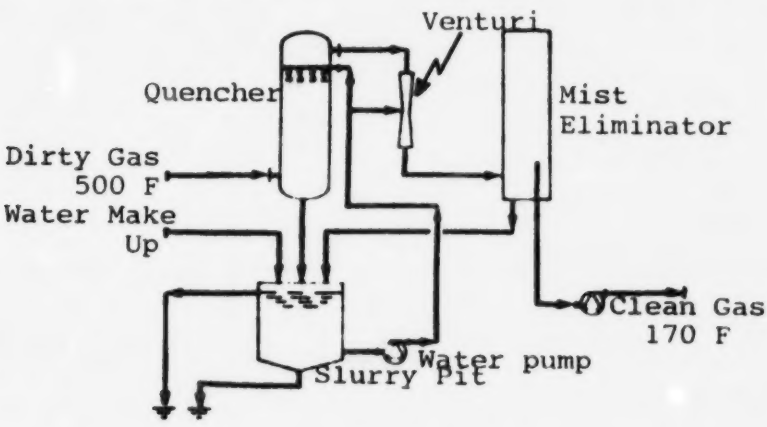
In general, gasifiers will be shop assembled and shipped out to the site. Transportation problems restrict the size of the gasifier. The general materiels of construction are mild steel shells with refractory or special steel liners. The refractory lining will probably be installed on-site either in the form of bricks or cast in place. High temperature nickel alloy steels are generally used in the grate assembly.

The gasifier will also require:

- Equipment for feedstock preparation including comminution and drying;
- Piping for the air and gas lines and their associated blowers;
- Ash handling facilities and disposal; and
- Gas cooling and cleaning, depending on the application.

The precise requirements are obviously a factor of the site and the application. In general all of the equipment is commercially available with the exception of the gas cleaning equipment which is designed for the given application. Figure 4 illustrates the process flow diagram for a modern gas scrubber unit.

Figure 4: Process Flow Diagram - Gas Scrubber System (from ref 3)



3.7 Gasifier Operations and Controls

The gasifier will require an auxilliary source of heat in order to establish the oxidation zone. Electric heating rods, propane and fuel oil burners or torches are generally used in Fixed Bed units. The Fluid Bed units are ignited by means of preheating the fluidizing air. The initial weak gas produced on start-up is usually flared in the emergency flare installed to take the gas in the event of interruption in its use.

The control and operation of gasifiers is based on some or all of the following parameters:

- The flue level;
- The temperature of the various sections;
- The oxygen content;
- The carbon monoxide level in the flue gas; and
- The pressure drop across the fuel bed.

The primary control is by varying the air feed as well as the rate of addition of the fuel. Ideally, the fuel gas should be monitored continuously. However, during a continuous operation a correlation will have been established between the fuel gas quality and one of the properties that can be monitored continuously, such as oxygen, carbon dioxide or carbon monoxide. On small gasifiers the method used before electronic chemical analysis came into being can be adopted. This was to have a small burner running on the producer gas and watched by the operator. A small flame, evidently, implied a weak gas thus calling for remedial action.

3.8 Gasifier Applications

Direct Firing- Close coupled applications, no gas clean up.

These applications are usually retrofit applications in which natural gas, LPG or fuel oil fired dry kilns or package boilers are modified to accommodate a low calorific value gas. These modifications normally include a heated burner shell to avoid the condensation of water vapour and tars along with a

reduction in the air flow and an increase in the size of the fuel gas burner pipe to accommodate a very low air to fuel ratio.

Clean Gas Application

These applications require the gases to be cleaned and cooled so that they can be piped over some distance and then burnt in space heaters, boilers or alternatively used to fire an engine to drive machinery or generate electricity.

Cooling is necessary to remove the excess water vapour, which can amount to as much as 550 litres (120 imperial gallons) of tar contaminated water for each tonne of green feedstock at 50% moisture content. The contaminated condensate will therefore represent a major disposal problem particularly since it carries a burden of phenolic compounds which are known to be extremely toxic to marine life. Solution of this problem still represents a major challenge and is the subject of research. The use of dry fuel reduces this problem. The Down-Draught gasifier will not tolerate more than 25-30% water and has a tar reforming capability. The low tar potential of the Fluid Bed gasifier using dry fuel along with the tendency to higher concentrations of methane makes it very competitive.

4.0 THE EXPERIMENTS

4.1 Plasma Processing Facility Description

The gasification of coal, peat, wood, tar sands and other carbonaceous materiels and the pyroprocessing of ores can be conducted very efficiently in the absence of oxygen using high powered plasma arc torches to provide the heat required.

A facility for plasma processing of such materiels has been built and is in full operation in the Resorption Canada Limited (RCL) laboratory. This facility was designed to optimize plasma processing parameters for a specific materiel. These parameters can then be scaled to production throughput rates with accuracy and low risks.

In 1979 non-transferred arc torches were developed by RCL's US affiliate. The torches strike an arc between two internal torch electrodes. The majority of the arc is external to the torch and the arc length is relatively fixed. A non-transferred arc torch can provide heat directly to the materiel being processed or it can be withdrawn for more indirect heating. Regardless of torch position the thermal power generated is variable over a dynamic range by adjusting arc current.

The RCL facility incorporates the first non-transferred arc torch employed in Canada. The torch, rated at 150KW, generates an arc which extends like a burner flame eight inches from the end of the torch. The arc edge temperature is 3000 deg C. Appendix H contains an explanation of how the plasma arc torch operates, its capabilities and a description of a Plasma Heating System.

In order to isolate the process from the external environment the materiel being processed must be introduced through a six inch port into a stainless steel reaction vessel

via a ram feeder. The cylindrical vessel is lined with 7.5 inches of refractory to ensure minimal thermal losses. Coupled with the torch's efficiency, the vessel design ensures the maximum possible conversion efficiency across a range of temperatures from less than 600 deg C to close to 3000 deg C.

If required, steam can be introduced into the vessel to provide sufficient hydrogen and oxygen radicals to enable total carbon gasification. Vessel geometry is such that the materiel to be processed, the steam and the torch arc enter the vessel at right angles to each other (see Figure 5). This feature enhances processing.

The vessel can also be tilted hydraulically up to 60 deg from the horizontal to ensure variable flow rates for a wide range of materiel homogeneity and density, thereby optimizing materiel dwell time in the pyrolysis zone near the arc.

These vessel features along with those of the torch make the facility one of the most flexible plasma processing designs in the world. It represents the culmination of seven years of processing experience gained since the plasma arc torch was first patented.

All components of the facility, except the torch, have been designed and manufactured in Canada. The facility can be trailer mounted and taken to the field. With the power supply interfacing at 600V AC, the facility can be utilized at any mine, mill or concentrator where this voltage exists.

The molten materiel and gas generated exit via a common eight inch diameter port. The gas is separated, cooled through a water scrubber and then sampled for analysis by a gas chromatograph before being flared. If steam is required by the process, the gas generated can fuel the boiler. The non-gaseous materiel can be sampled for analysis and

subsequently quenched to a frit, poured into moulds or used as input to another process.

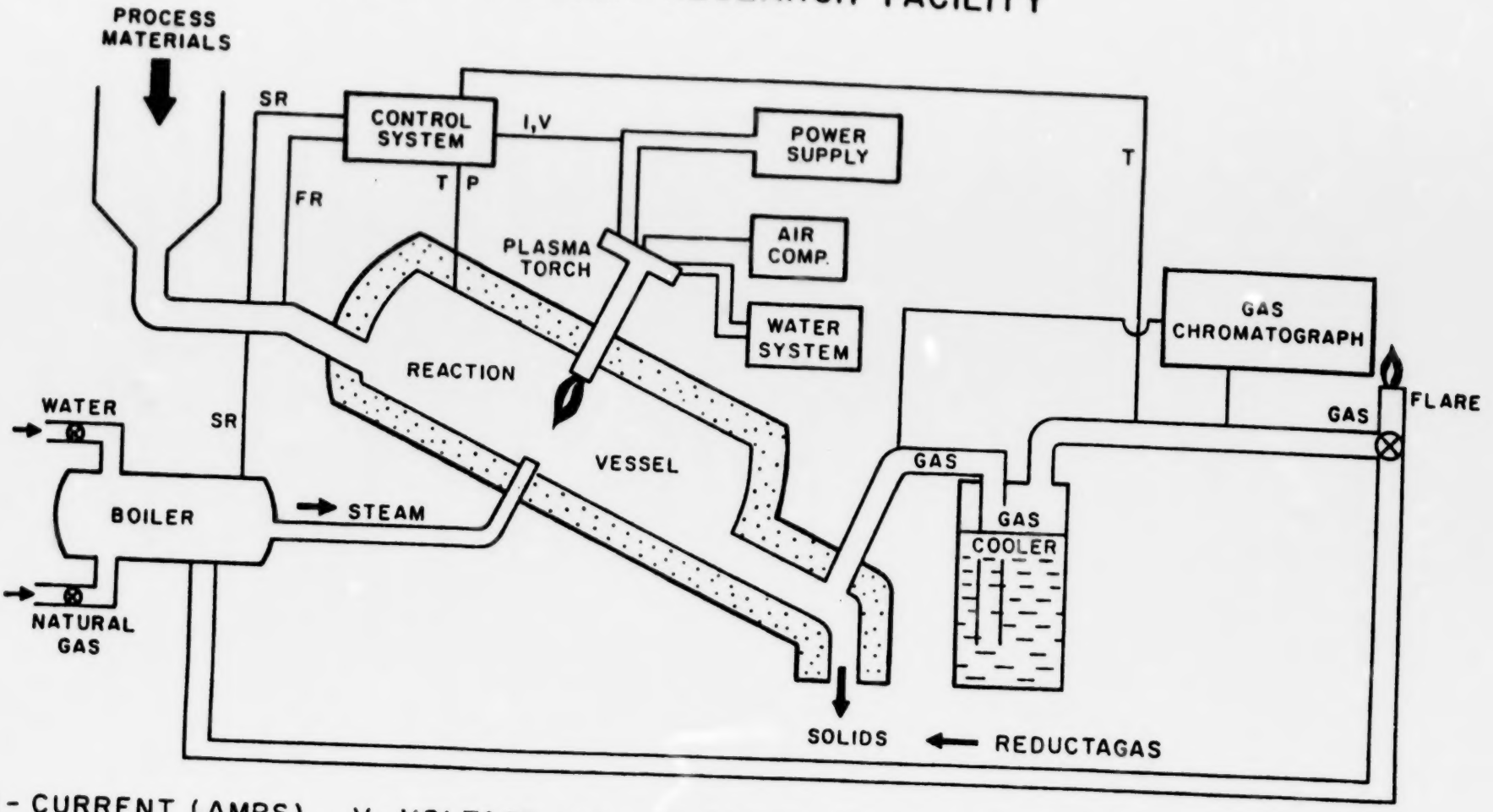
The control system is very versatile and enables one operator to process from 100-200 lbs per hour of materiel in the facility depending on its thermal requirements. The control system gives the operator continuous readout of: torch position, current, voltage, air flow rate, coolant water flow rate, materiel feed rate, process temperature, reaction vessel input and output temperatures, scrubber output temperature and reaction vessel pressure. If any of these parameters exceeds tolerance levels, the torch is instantaneously interlocked off.

As the amount of air introduced into the torch is considerably less than the amount required for stoichiometric combustion, plasma processing approaches pure pyrolysis. Thus, the plasma process can be contained in a one-stage system that is smaller than comparable combustion based processes. Consequently, capital costs tend to be up to 40% lower than capital costs for combustion based systems of similar throughput.

The high process temperatures achieved by plasma processing ensure rapid and complete breakdown of chemical bonds and avoid the particulates and partially combusted hydrocarbons normally associated with combustion processes. Total gasification can be achieved very efficiently. The general absence of oxygen results in significantly less air pollution from contaminants such as nitrous oxides (NOx) and sulphur dioxide (SO2) than is associated with conventional gasification processes.

RESORPTION
CANADA LIMITED

FIGURE 5: PLASMA RESEARCH FACILITY



I - CURRENT (AMPS) V - VOLTAGE (V) T - TEMPERATURE (DEGREES C) P - PRESSURE (PSIG)
FR - MAT'L FEED RATE (LBS/HR) SR - STEAM RATE (LBS/HR)

Research programs have been completed to optimize the plasma process for the gasification of high quality anthracite, peat, municipal solid waste and silver recovery from x-ray film. The research program described herein will greatly support the optimization of the plasma process for wood waste gasification.

4.2 Actual Experimental Procedure

The materiel to be processed was preweighed and fed into the vessel after the vessel had been preheated to about 40 deg C above the intended processing temperature. This was done because the time taken to open the feed port, feed the materiel and close the feed port to enable start up caused the vessel to cool to a temperatuiure slightly below the desired temperature. Starting to process at this temperature was desirable since by the end of the experiment the temperature had risen to above the desired temperature. Experience enabled prediction of these temperatures so that the average temperature of processing was as close as possible to the prescribed temperature. At the end of the run the temperature was again allowed to rise about 40 deg C above the planned temperature for the next run.

The system enabled the operators to sample the produced gas at any one of two different stages (see Figure 6). The sampled gas was analysed by Forintek Canada Corporation. The volume of gas produced was recorded using a Bailey gas meter. The temperature of the vessel was recorded at three different points and the product gas temperature was recorded at the point of the producer gas exit from the vessel. The voltage drop across the torch and the current were recorded to enable the calculation of the power and thus the heat delivered to the materiel and the vessel refractory surface. The flowrate of the air used to provide the plasma was recorded as it was often changed to force a change in the torch characteristics as well as to promote longer electrode life.

4.3 Project Requirements

A list of the project requirements as they appear in the original project proposal are enclosed as Appendix A.

Only 16 of the required 60 runs had actually been performed by the original contract expiration. These 16 runs were performed with the hogged fuel as received, with approximately 50% moisture content. The remainder of the runs were rescheduled through an extension amendment to the contract. Hogged fuel was used throughout. Experience gained on the first 16 runs necessitated this schedule and requirements change in order to achieve more beneficial results in the minimum amount of resources available. Utilization of crushed poplar was judged uneconomical. The rescheduling called for a total of 23 successful runs in accordance with the requirements enclosed in Appendix A. Appendix A also provides information as to which runs were performed for each of the rescheduled requirements.

5.0 EXPERIMENTAL RESULTS

5.1 Fuel and Gas Analyses

The analysis of the four different types of fuel used are contained in Appendix B. The types of fuel used are:

1. As received - with 50.68% moisture content;
2. Wood #1 - dried for one week;
3. Wood #2 - dried for two weeks; and
4. Wood #3 - dried for three days.

The gas analyses reports of representative runs are enclosed as Appendix C.

5.2 Experiments Performed For Original Requirements

Sixteen runs were performed with a 50% moisture content in the hogged fuel. Analysis of the gas produced in the first five runs did not yield good results because the gas samples were allowed to stand for a number of days prior to being analyzed. This allowed the light portion of the sample, the H2, to escape and air to seep through and contaminate the samples for runs 1, 2, 3, 4 and 5).

Better planning to obtain gas analyses in the next four runs yielded more encouraging results, which are summarized in Appendix D. The progress report submitted at this point included several points of discussion regarding process efficiency, which are also enclosed in Appendix D.

Experience gained from these four runs and the operation at higher temperatures improved the gasification yields even further in runs 10 through 16. A progress report written after completion of the 16th run included notes on conclusions and inferences as to how to proceed with getting a better appreciation of the results. These notes are enclosed at Appendix E.

5.3 Rescheduling of Experiments

The rescheduling of the project requirements was made after mutual agreement between the Scientific Authority and RCL. This was done to produce gasification results that could more easily be utilized to examine the effect of changing the conditions of the experiments in a prescribed and systematic way. The parameters to be investigated were temperature, use of steam, power level, dryness level and the amount of fuel used (see Appendix A). It was also agreed that better interpretation of the results would be possible if more gas samples were taken for each run. This would enable graphical representation of gas volume, heating value and power vs time since the two or three gas samples taken in the earlier runs were not representative of the complete span of the run. For convenience the next 23 runs were labelled runs 21-43. The gas analysis results for some of these runs are in Appendix C.

A computer program was written to calculate the Corrected Volume (VC) (after temperature compensation) the Heat Content of the Gas Produced in BTU/hr (HC), the Total Power Utilization in BTU (HPT), the Total Heat Content of the Gas in BTU (HO) and the Total Heat Input in BTU (HTI) as well as the Efficiency (EFF). Tables of input data and output results are presented in Appendix F. Due to the fact that the Bailey gas meter range is 0-10,000 SCFH, the number "9999" was used in the input data table to denote a flowrate greater than 10,000 SCFH. Interpolation was used to fix Temperatures and/or Heating Values for certain incomplete data lines.

Plots of the Corrected Volume (SCFM), Heating Value (BTU/SCF), Power Utilization (BTU/Hr), Gas Heat Production (BTU/Hr), Total Heat Input to Point of Reference (BTU), Total Heat Output to Point of Reference (BTU), and Efficiency Against Time were plotted. Representative samples of these plots are presented in Appendix G. Arrows show the periods of time during which steam injection was taking place.

5.4 Interpretation of Results

The graphs show a decreasing efficiency towards the end of each run. This means that towards the end of the run there is not enough fuel in the vessel to produce good quality gas and the heat input of the torch is merely used to raise the temperature of the vessel instead of being utilized to promote gasification. In reality this should not be allowed to happen as it is uneconomical but it was required through these runs to completely gasify the fuel remnants for safety purposes when the vessel was opened to commence the next run. It was also used to raise the temperature of the vessel to that required to commence the next run.

The maximum efficiency for each run has been calculated which shows the point at which the process starts to have a negative efficiency. These results are presented in Table 8.

Table 8: Summary of Results At Time of Maximum Efficiency.

Run#	Time (min)	Heating Value of Output Gas (BTU)	Total Heat Input (BTU)	Efficiency (%)
21	37	667,154	804,658	82.9
22	35	698,295	810,717	86.1
23	33	610,692	882,503	69.2
24	36	531,366	886,542	59.9
25	44	546,112	873,629	62.5
26	53	725,410	897,833	80.8
27	60	388,659	800,631	48.5
28	45	466,460	692,175	67.4
29	40	431,221	869,083	49.6
30	14	279,725	417,865	66.9
31	35	590,692	754,323	78.3
32	28	266,782	580,379	46.0
33	28	381,353	577,137	66.1

Table 8: Continued

Run#	Time (min)	Heating Value of Output Gas (BTU)	Total Heat Input (BTU)	Efficiency (%)
34	37	905,634	906,783	99.9
35	38	827,948	952,407	86.9
36	53	1,125,754	1,065,459	105.7
37	60	1,149,293	822,867	139.7
38	51	956,617	948,347	100.9
39	44	885,808	811,329	109.2
40	68	1,172,215	1,181,417	99.2
41	60	1,060,161	929,012	114.1
42	58	976,992	750,204	130.2
43	70	1,394,854	1,103,272	126.4

The efficiency of runs utilizing steam injection is grossly exaggerated due to the fact that any steam not taking part in the reaction was expelled and measured as additional gas flow. Subsequent inability to account for it when analyzing the gaseous products yielded a higher than actual total heating value.

Additional points which should be borne in mind as these results are studied are:

1. Moisture contents of Type 1 and Type 2 wood were close. It seems that the environment they were left to dry in did not allow the wood to dry beyond 25% moisture content;
2. Runs 24, 25 and 26 were used to compare gas yields at three different power levels. The rate of gas production in run 24 was clearly faster. It was hence decided to perform the remainder of the runs at as high a power level as possible;
3. Runs 34 and 35 were used to compare gas yields with run

36 at three different steam rates. Run 36 was clearly superior. It was therefore decided to carry out the remaining runs at a high steam rate;

4. Runs 37, 40, 41, 42 and 43 were carried out at a lower than originally decided power level because the torch electrode design changed thus changing the voltage and current characteristics of the torch;
5. The chosen temperature was 900 deg C since faster reaction rates were observed at this temperature;
6. Whenever 150 lbs and 100 lbs were called for in the requirements, 100 lbs and 67 lbs respectively were used in the actual experiments. This was due to the fact that a certain volume of fuel in the wet state (original materiel) weighed only two thirds as much when dry while not losing practically any of its original volume. Hence, an attempt to use 150 lbs of dry fuel would fill the vessel up to a degree that might obstruct the torch from starting up; and
7. Heat input to turn water to steam was taken as 1102.4 BTU/lb with an 80% heat delivery to the water, ie. 1102.4/0.80.

5.5 Comparison Between Runs

Comparing runs which were performed under the same conditions but with differing amounts of fuel will enable determination of the incremental amount of fuel heating value, electricity consumption and total gas heating value. This will give a better knowledge of what the efficiency would be under steady state conditions of continuous feeding.

The incremental amounts of the aforementioned variables are in fact those amounts that were actually measured when the incremental amount of fuel was gasified with an adequate amount of fuel being present to approach the steady state conditions of continuous feeding. The runs to be compared are presented in Table 9.

Table 9: Comparison Between Runs

Fuel/Temperature	100 lbs	67 lbs
1. Wood #1, 700 deg C	21	32
2. Wood #1, 800 deg C	22	33
3. Wood #1, 900 deg C	23	27
4. Wood #2, 900 deg C	29	28
5. Wood #3, 900 deg C	31	30

No attempt was made to compare runs performed under steam injection conditions since the results were in error due to steam dilution of the gas.

Incremental efficiencies of these runs would again be in error due to the following interesting observation. Efficiencies of runs utilizing steam and less fuel appear to be greater than those of corresponding runs and a greater amount of fuel. The reason appears to be the inflated values of the gas heat content under steam injection conditions which do not increase proportionally to the amount of fuel used but in accordance with the amount of time steam injection was allowed to proceed. On the other hand, the denominator portion in the efficiency calculation did increase proportionally to the amount of fuel used.

Table 10 compares the efficiencies of corresponding steam injection runs which clearly indicates that the efficiencies of runs using 67 lbs of fuel are higher than corresponding ones using 100 lbs of fuel.

Table 10: Comparison of Steam Injection Runs

100 lbs		67 lbs	
Run#	Eff (%)	Run#	Eff (%)
36	105.7	37	139.7
40	99.2	41	114.1
43	126.4	42	130.2

The comparison of corresponding runs is presented in Table 11. The method of obtaining incremental heat input and output data will be explained by a sample step-by-step analysis of the comparison of runs 21 and 32 contained in this table.

Table 11: Comparison of Corresponding Runs

Characteristic	Runs Being Compared			
	21/32	22/33	23/27	31/30
a. Cut Off Point (minutes of run appearing first)	19.15	10.21	6.84	12.22
b. Incr Fuel Heat Value (BTU)	180,906	180,906	180,906	147,048
c. Incr Elect Consumption (BTU)	132,898	76,926	70,453	108,111
d. Incr Tot I/P Energy(b+c,BTU)	313,804	257,832	251,359	255,159
e. Incr Tot Gas H.V. O/P (BTU)	400,373	316,942	222,033	310,967
f. Incr Efficiency (e/d,%)	127.6	122.9	88.3	121.9

Incremental results from comparing runs 29 and 28 were inconclusive because both runs had the same HO value at the point of maximum efficiency. The efficiency of run 29 was too low hence comparison was not beneficial.

At the point of maximum efficiency of run 32, HO = 266,781.8 BTU. At the point of maximum efficiency of run 21, HO = 667,154.3 BTU. Subtracting one from the other gives 400,372.5 BTU. This is the incremental amount of BTUs that run 21 produced additional to the number of BTUs produced by run 32. This means that the extra amount of fuel utilized in run 21 was used at the beginning of the run to produce an extra 400,372.5 BTU before conditions identical to run 32 were brought about by having exactly 33 lbs of fuel gasified. This value of HO appears between the fourth and fifth line in the table of results of run 21. It is

$$\frac{400,372.5 - 249,337.3}{421,142.9 - 249,337.3} \times 100 = 87.9\%$$

of the way between the thirteenth and twentieth minute after start-up which is equivalent to minute 19.15. The electricity consumed by this time is

$$\text{Incr HPT} = (138,795.3 - 90,017.8)(0.879) + 90,017.8$$
$$= 132,898.4 \text{ BTU}$$

The incremental amount of fuel used is 33 lbs of fuel #1 which is equivalent to 180,906 BTU. Therefore, the incremental efficiency is

$$\frac{400,372.5}{132,898.4 + 180,906} \times 100 = 127.6\%$$

6.0 CONCLUDING MATERIAL

6.1 Observations/Conclusions

Production of a gas of heating value 250-300 BTU/cu ft indicates optimism in the competitiveness of plasma gasification of biomass (compare to 125-175 BTU/cu ft for conventional gasifiers in Table 6). Further optimization, concentrating on minimizing the electricity consumption, is needed. A small modification to the existing facility would enable continuous feeding which would enable continuous processing under the conditions which achieved maximum reaction rates in these experiments.

Processing under such conditions would be simple since materiel is fed slowly and continuously to keep the temperature of processing constant. This means that just enough materiel must be input that can be gasified by the input torch energy.

Generally, the incremental efficiency is greater than the efficiency of either of the runs compared. This proves a suspected trend of better gasification efficiency - there must be an adequate amount of fuel in the vessel at all times in order to keep the reaction rates as high as possible. Ideally, this means that all the energy input by the torch is utilized to gasify the materiel and none of it is used to heat up the refractory. This is the condition of steady-state operation under continuous feeding conditions.

The necessity of condensing the water vapours present in the product gas is clearly evident from the grossly exaggerated efficiencies of experiments utilizing steam injection. The efficiencies of experiments without steam also appear high due to the fact that some water which evaporates at the beginning of the run when the wet materiel is heated does not take part in the reaction, but is measured as additional gas volume. This, though, is not as high as in the

case of steam injection experiments.

Corresponding experiments, or experiments that will be directly compared to prove a certain assumption, should be performed during the same period of time. This should be done so that the parameters of power, air and length of the runs are monitored as precisely as possible in order that they can be kept exactly the same if needed.

In large production systems the impact of gas dilution will be lessened. This is due to the fact that utilization of larger torches will be possible which inherently require less air to deliver the same amount of heat thus causing dilution of the product gas to a much lesser degree.

The ability to start, shut down or increase the power of the torch within seconds is very advantageous. The operator can initiate, stop, restart or accelerate the gasification reaction any time he so chooses, or decides necessary, within seconds and without adverse consequences to any portion of the equipment.

The system has built in controls which automatically turn the torch off if certain parameters (water coolant flow, airflow, temperature, etc) exceed tolerance levels. This avoids damage to the torch and the rest of the equipment as well as eliminating any danger the operator may be facing from such cases as the overheating of the gasifier, a common occurrence in many conventional gasifiers.

A great advantage of the plasma processing system stems from the fact that the heat required for gasification is input by an external source of heat. This means that exactly the amount of heat required for best gasification is input without having to change any of the other parameters essential for best gasification results. Conventional gasifiers utilizing

steam injection usually require the injection of considerably more steam than actually required in order to keep the temperature in control, stopping it from creeping to unsafe limits, which in turn brings about conditions that yield non-optimal gasification results.

Whereas conventional gasifiers require cumbersome controls and very expensive equipment to monitor and control their gasification process, the control system for a plasma gasifier reactor is very simple and inexpensive. Even large plasma gasifiers can be efficiently monitored and controlled by exactly the same control system that a small gasifier is equipped with, ie as with the RCL Plasma Research Facility.

As received feedstock can be processed in the plasma gasifier, even with moisture contents in excess of 50%. Compared to the Fluidized Bed gasifier which can only process materiels with less than 25% moisture content, the plasma gasifier proves its superiority in this area.

In summary, the following conclusions are evident from the results obtained through this experimentation:

1. Plasma arc gasification is feasible and highly competitive;
2. Continuous feeding could very simply optimize processing efficiency;
3. Maximum gasification efficiency must be monitored very closely to ensure no input heat is wasted;
4. Water vapour will virtually always be present in the product gas if the feedstock moisture content is high or if steam injection is used in the process;
5. Water vapour in the product gas must be condensed to prevent erroneous statistics and dilution of the product gas;
6. Experiments which will be directly compared must be performed during the same period of time;

7. Large plasma systems will cause much less dilution of the product gas due to their requirement for less airflow for the same heat input;
8. Plasma gasifiers are very efficient and responsive to process change requirements;
9. Plasma gasifiers can be very efficiently, effectively and economically controlled;
10. Plasma gasifiers can most advantageously control the amount of heat input to the process to optimize gasification results; and
11. Plasma gasifiers can process feedstock with virtually any moisture content.

6.2 Recommendations

Through this series of experiments it was obvious that the efficiency of the plasma gasifier could be considerably higher that was calculated under the conditions of these tests. It is therefore recommended that a continuation of this project be conducted to determine the exact efficiency characteristics of plasma gasifiers.

7.0 LIST OF REFERENCES

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APPENDIX A

PROJECT REQUIREMENTS

PROJECT REQUIREMENTS

1.0 Project Original Requirements

Fuel Type	Moisture Content	Total Runs
Hogged Fuel	62% (as received)	20
	12% (batch dried)	20
Crushed Poplar	(as received)	20
TOTAL RUNS		60

2.0 PROJECT RESCHEDULED REQUIREMENTS

Project Requirement	No. of Runs
1. Study the effect of temperature: Use 150 lbs of Wood #1 @ each of 700, 800, 900 deg C	3
2. Study the effect of steam use: Use 150 lbs of Wood #1 @ one temp chosen from 1 @ 3 steam rates	3
3. Effect of power level: Use 150 lbs of Wood #1 and process @ temp chosen from 1 @ 3 power levels	3
4. Use 100 lbs of Wood #1 @ chosen temp from 1 and power level chosen from 3	1
5. Use 100 lbs of Wood #1 @ chosen temp from 1, steamrate from 2 and power level from 3	1
6. Use 100 lbs and 150 lbs resp of Wood #2 without steam, power level from 3 and temp from 1	2
7. Same as 6 but for Wood #3	2
8. Same as 4 but @ the two omitted temps	2
9. Same as 5 but @ the two omitted temps	2
10. Same as 6 but with steam calculated from 2	2
11. Same as 10 but for Wood #3	2
TOTAL RUNS REQUIRED	23
CONTINGENCY - 33% (see note)	8
TOTAL RUNS TO BE PERFORMED	31

NOTE: One out of three runs is expected to have to be repeated due to unexpected difficulties in the proper execution of the experimental procedure. A 33% contingency margin has been used for this reason.

3.0 RUNS FOR RESCHEDULED REQUIREMENTS

Run#	Explanation
21	Requirement 1, 700 deg C
22	Requirement 1, 800 deg C
23	Requirement 1, 900 deg C
24	Requirement 3, High Power
25	Requirement 3, Medium Power
26	Requirement 3, Low Power
27	Requirement 4
28	Requirement 6, 100 lbs
29	Requirement 6, 150 lbs
30	Requirement 7, 100 lbs
31	Requirement 7, 150 lbs
32	Requirement 8, 700 deg C
33	Requirement 8, 800 Deg C
34	Requirement 2, Low Steam
35	Requirement 2, Medium Steam
36	Requirement 2, High Steam
37	Requirement 5
38	Requirement 9, 700 Deg C
39	Requirement 9, 800 deg C
40	Requirement 10, 150 lbs
41	Requirement 10, 100 lbs
42	Requirement 11, 100 lbs
43	Requirement 11, 150 lbs

NOTE 1: Low steam = 60-80 lbs per hour at 11 psig
Medium steam = 100-120 lbs per hour at 11 psig
High steam = 140-150 lbs per hour at 11 psig

NOTE 2: The air flowrate utilized influences the quality of the gas (heating value) as well as its volume. Low air gives high heating value (low dilution) and less volume of total gas production.

NOTE 3: High power gives faster reaction rates.

APPENDIX B

FUEL ANALYSES

FUEL ANALYSES

1. Report on Resorption Canada Fuel Sample (Hogged Fuel)

A. Moisture Content (wet basis)

(on arrival)	(when tested)
1. 50.36%	1. 5.85%
2. 51.00%	2. 5.75%
Average 50.68%	3. 5.80%

B. Heating Value

A. Oven Dried Basis

1. 4663 cal/gm	8393 BTU/lb
2. 4660 cal/gm	8388 BTU/lb
Average 4661.5 cal/gm	8391 BTU/lb

B. Heating Potential in wet state 3199 BTU/lb

C. Ash Content

1. 3.38%
2. 3.15%

Average 3.27%

D. Elemental Analysis

	#1	#2	Average
%N	0.360%	0.525%	0.443%
%C	48.816%	49.659%	49.238%
%H	5.643%	5.793%	5.718%
%O	41.911%	40.753%	41.332%

2. Report on Resorption Canada Wood Residue: Wood #1

A. Moisture Content

(on arrival)	(when tested)
1. 25.90%	1. 9.08%
2. 25.34%	2. 8.99%
Average 25.62%	3. 9.035%

B. Heating Value

A. Oven Dried Basis

1. 4679 cal/gm	8422 BTU/lb
2. 4706 cal/gm	8471 BTU/lb
Average 4693 cal/gm	8447 BTU/lb

B. Heating Potential in wet state (25.62% M.C.) 5482 BTU/lb

C. Ash Content

1. 3.90%
2. 3.93%

Average 3.915%

D. Elemental Analysis

	#1	#2	Average
%N	0.571%	0.79%	0.681%
%C	48.756%	50.045%	49.401%
%H	5.662%	5.877%	5.770%
%O(by difference)	41.096%	39.373%	40.234%
%ash	3.915%	3.915%	3.915%

3. Report on Resorption Canada Wood Residue: Wood #2

A. Moisture Content

(on arrival)	(when tested)
1. 27.06%	1. 10.46%
2. 27.40%	
Average 27.23%	

B. Heating Value

A. Oven Dry Basis

4691 cal/gm 8444 BTU/lb

B. Heating Potential in wet state (27.23% M.C.) 5335 BTU/lb

C. Ash Content

3.37%

D. Elemental Analysis

%N	0.420%
%C	50.483%
%H	5.989%
%O(by difference)	39.738%
%ash	3.37%

4. Report on Resorption Canada Wood Residue: Wood #3

A. Moisture Content

(on arrival)	(when tested)
1. 37.15%	1. 10.48%
2. 35.83%	
Average 36.49%	

B. Heating Value

A. Oven Dried Basis

4651 cal/gm 8372 BTU/lb

B. Heating Potential in wet state (36.40% M.C.) 4456 BTU/lb

C. Ash Content

3.04%

D. Elemental Analysis

%N	0.575%
%C	52.038%
%H	5.645%
%O(by difference)	38.702%
%ash	3.04%

APPENDIX C

GAS ANALYSES

Forintek Canada Corp. Eastern Forest Products Laboratory 800 chemin Montreal Road, Ottawa, Ontario K1G 3Z5 Telephone (613) 744-0963 Telex 053-3606

APPENDIX C

GAS ANALYSIS REPORT

Source: Resorption Canada

Date Received: April 4, 1983 Date Analyzed: April 6, 1983

Sample No.	H_2	CO_2	Hydrocarbons	O_2	N_2	CH_4	CO	Total
13-1	33.33	12.17		3.36	26.00		24.81	99.67
14-1	24.27	12.50		5.76	29.72		22.21	94.46
14-2	34.86	11.84		3.63	22.54		21.37	94.24
14-3	24.98	8.11		4.29	29.30		26.60	93.28
15-1	39.69	12.82		2.97	23.64	1.17	23.26	103.55
16-1	40.29	15.85		1.60	20.37	1.80	17.68	97.59
16-2	39.90	14.98		1.52	23.21		19.61	99.22
16-3	37.07	14.08		1.57	27.11		21.78	101.61
Room Air				21.00	78.01			99.01

NOTES: Samples 14-5 and 16-4 were not analyzed since there was not enough gas in the bags for proper analysis.

All samples also contained small amounts of ethylene and acetylene.

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APPENDIX C

GAS ANALYSIS REPORT

Source: Resorption Canada Ltd.

Date Received: September 9, 1983 Date Analyzed: September 9-12, 1983

Sample No.	H_2	CO_2	Hydrocarbons C_2H_6	Hydrocarbons C_2H_4	O_2	N_2	CH_4	CO	Total
26-1	49.29	11.05	-	0.46	2.30	15.36	3.13	28.09	109.69
26-2	54.09	11.19	-	0.19	1.49	15.13	2.07	27.78	111.94
26-3	50.07	8.48	-	0.11	2.45	16.24	1.83	30.09	109.27
26-4	31.09	3.66	-	-	1.34	31.95	0.37	35.37	103.78
26-5	52.36	9.16	-	0.06	0.79	15.00	1.50	33.04	111.90
26-6	43.21	6.21	-	-	1.07	21.94	0.72	35.06	108.21
26-8	4.67	0.13	-	-	12.37	52.47	0.15	29.46	99.25
Room Air					20.91	78.37			99.28

NOTES:

Forintek Canada Corp. Eastern Laboratory 800 chemin Montréal Road, Ottawa, Ontario K1G 3Z5 Téléphone (613) 744-0963 Télex 053-3606

APPENDIX C

GAS ANALYSIS REPORT

Source: Resorption Canada Ltd.

Date Received: October 19, 1983 Date Analyzed: October 19-21, 1983

Sample No.	H_2	CO_2	Hydrocarbons C_2H_6	Hydrocarbons C_2H_4	O_2	N_2	CH_4	CO	Total
40-1	44.64	11.51	0.13	1.11	2.52	18.24	4.79	28.82	111.76
40-2	53.48	11.12	0.06	0.62	1.05	14.89	3.24	31.31	115.77
40-3	47.30	19.13	0.09	0.91	3.41	25.33	3.90	11.74	111.82
40-4	49.98	19.58	0.06	0.63	2.96	24.88	3.22	10.42	111.73
40-5	43.67	22.59	0.06	0.56	2.12	32.38	2.63	4.25	108.26
40-6	29.71	7.91	-	0.09	3.13	39.06	0.91	26.17	106.98
40-7	48.48	22.16	0.02	0.27	1.49	32.43	1.61	6.42	112.87
40-8	47.93	20.47	-	0.26	1.81	30.11	1.69	9.90	112.17
40-9	8.02	2.91			6.79	60.37	0.47	23.00	101.09

NOTES:

Forintek Canada Corp. Eastern Laboratory 800 chemin Montréal Road, Ottawa, Ontario K1G 3Z5 Téléphone (613) 744-0963 Télex 053-3606

APPENDIX C

GAS ANALYSIS REPORT

Source: Resorption Canada Ltd

Date Received: October 19, 1983 Date Analyzed: October 19-21, 1983

Sample No.	H_2	CO_2	Hydrocarbons C_2H_6	Hydrocarbons C_2H_4	O_2	N_2	CH_4	CO	Total
43-1	51.66	14.01	0.05	0.74	0.48	15.75	3.69*	26.33	112.71
43-2	50.12	14.30	0.07	0.89	0.66	16.91	3.94	25.41	112.30
43-3	52.30	21.30	0.03	0.64	0.73	23.25	2.83	11.96	113.04
43-4	45.32	20.74	0.03	0.61	1.09	27.45	2.64	10.74	108.62
43-5	8.46	9.08	-	0.06	6.38	54.94	0.62	20.80	100.34
43-6	41.49	23.30	-	0.22	0.64	35.03	1.21	5.51	107.50
43-7	38.78	22.17	0.02	0.31	0.82	35.98	1.49	7.20	106.77
43-8	13.95	9.80	-	0.04	1.27	52.70	0.51	22.19	100.46

NOTES:

*estimation based on peak height measurement

APPENDIX D

PROGRESS REPORT

AFTER COMPLETION

of

NINTH RUN

APPENDIX D

PROGRESS REPORT AFTER COMPLETION OF NINTH RUN

1. Data Summary

CHARACTERISTIC	RUN#6 (AVERAGED)	RUN#7 (AVERAGED)	RUN#8 (AVERAGED)	RUN#9 (AVERAGED)
a. Temperature Range (deg C)	720-840	760-900	760-940	850-940
b. Length of Run (min)	38	49	85	53
c. Average Torch Power (KW)	167.2	180	155.8	167.9
d. KWHr Consumption	106	147	221	148
e. Amount of Fuel Used (lbs)	50	100	150	100
f. Heating Value of Fuel Used (BTU)	159,965	319,930	479,895	319,930
g. Total Volume of Gas Produced (cu ft)	1900	3400	5950	4050
h. Heating Value of Gas Produced (BTU/cu ft)	158.44	177.07	196.66	172.24
j. Total Heating Value of Gas (BTU)	301,036	602,038	1,170,127	697,572
k. Efficiency (j/(f+d))X100 (%)	57.7	73.3	94.8	84.6

2. Discussion

The efficiency figures appear quite high. This can be attributed to the fact that the gas samples used were taken early in each run, when there was enough materiel in the vessel and the gas produced was of high quality. As the amount of materiel available decreases, due to its gradual conversion to gas, the gas produced should be of lower quality and hence the total heating value of the gas will be somewhat lower than the value calculated in the above table. However, the amount of gas produced at the first stage of each run is considerably more than the gas produced at the end, hence, the efficiency should not decrease dramatically.

It can be noticed that better quality gas and higher efficiency generally results when higher temperatures and/or a greater amount of materiel is utilized.

Other factors which will affect efficiency are as follows:

Increase Efficiency

- At the end of the run the majority of electricity was absorbed by the furnace walls and not by the materiel to be processed because gradually less materiel was available as the time progressed. Using a continuous feeding process (future planning) so as to always supply enough materiel for optimal conditions will solve this problem. By utilizing the same amount of electricity to process a greater amount of fuel, more and better quality gas is produced, hence, the efficiency increases.
- In future planning, utilization of larger torches implies lower utilization of airflow through the torch for the same amount of heat delivered. This will solve

the problem of dilution of the gas with O2 and N2 and will provide less O2 to the process so that more CO and less CO2 will be produced.

Decrease Efficiency

- Gas produced is above ambient temperature, therefore, when analyzed it is less in volume than when produced. Calculating the volume of gas produced at NT will give us a lower figure and, hence, a lower efficiency.

APPENDIX E

PROGRESS REPORT

AFTER COMPLETION

of

SIXTEENTH RUN

APPENDIX E

PROGRESS REPORT AFTER COMPLETION OF SIXTEENTH RUN

1. Data Summary

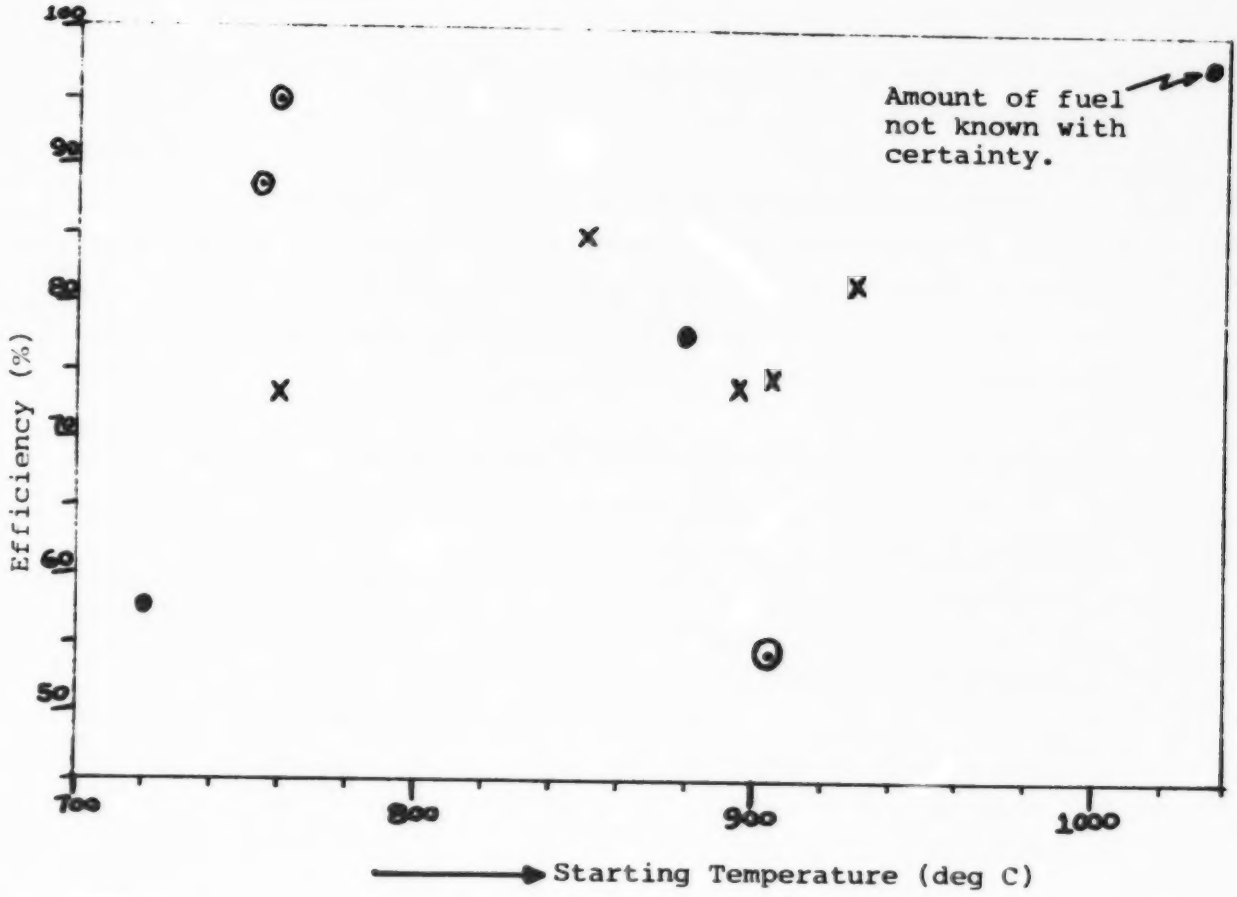
CHARACTERISTIC	RUN#10 (AVER 1&2)	RUN#11 (1 SAMPLE)	RUN#12 (1 SAMPLE)	RUN#13 (1 SAMPLE)
a. Temperature Range (deg C)	755-960	880-995	895-900	905-1025
b. Length of Run (min)	81	45	28	65
c. Average Torch Power (KW)	165.6	175.5	169.1	176
d. KWHr Consumption	223.6	131.6	78.9	190.7
e. Amount of Fuel Used (lbs)	150	50	100	100
f. Heating Value of Fuel Used (BTU)	479,895	159,965	319,930	319,930
g. Total Volume of Gas Produced (cu ft)	5750	2800	2200	2775
h. Heating Value of Gas Produced (BTU/cuft)	194.04	168.83	197.36	174.80
j. Total Heating Value of Gas (BTU)	1,115,701	472,065	434,192	484,890
k. Efficiency (j/(f+d))X100 (%)	88.3	77.5	73.7	74.5

Data Summary CONT

CHARACTERISTIC	RUN#14 (AVERAGED)	RUN#15 (1 SAMPLE)	RUN#16 (AVERAGED)
a. Temperature Range (deg C)	905-1085	930-1070	1035-1140
b. Length of Run (min)	80	67	39
c. Average Torch Power (KW)	166.4	167.7	174.8
d. KWHr Consumption	221.8	187.3	113.6
e. Amount of Fuel Used (lbs)	150	100	50
f. Heating Value of Fuel Used (BTU)	479,895	319,930	159,965
g. Total Volume of Gas Produced (cu ft)	4100	4060	2950
h. Heating Value of Gas Produced (BTU/cu ft)	164.42	192.42	181.66
j. Total Heating Value of Gas (BTU)	674,122	781,225	535,897
k. Efficiency (j/(f+d))X100 (%)	54.5	81.4	97.8

APPENDIX E

Graph of Efficiency Vs Starting Temperature
For Various Batch Sizes
(Runs 6-16)



. 50 lbs used
X 100 lbs used
● 150 lbs used

2. Discussion

The appropriate method of getting optimal efficiency (ie. at optimal, steady-state conditions) is to calculate the difference in volume of gas produced and electricity used between corresponding runs utilizing 150 and 100 lbs of materiel respectively. It is best to use the starting temperature figure.

The gas temperature at exit is about 40-50 deg C. Therefore the error is not considerable and it can be easily corrected using Gas Laws.

Generally, efficiency increases with increased amount of fuel used. Increased efficiency for increased temperature is not as evident above 800 deg C as it is below 800 deg C. It could be that increased heat losses counterbalance the increased rate of gas production.

The efficiency calculation depends on the point at which the run is decided to have ended.

Compare Run 13 & Run 14

Additionals Used: 159,965 BTU materiel
31.06 KWHrs

Additional Produced: 187,350 BTU of gas
Differential Y = 70.44%

This should be greater since the gas produced at the beginning of a run has greater BTU value than the gas produced at the end.

Compare Run 7 & Run 10

Additionals Used: 159,965 BTU materiel
76.6 KWHrs

Additional Produced: 2350 scf X 177.07 BTU/scf (run 7)
= 416,115 BTU
Differential Y = 98.7%

APPENDIX F

COMPUTER ANALYSES

OF

RESULTS

Computer Analyses of Results

1. General

This Appendix contains the following documents in support of the computer analyses of results:

- The definition of variables used;
- The definition of symbols used;
- A copy of the computer program used to calculate the variables as well as the create plots of them; and
- A copy of the printout table of input data and output results for each run.

2. Variable Definitions

IT = Time after start-up (minutes)
ISN = Sample number (0 indicates no sample taken)
IVT = Vessel temperature (degrees C)
IP = Power (KW)
AF = Airflow (scfm)
AP = Air pressure (psig)
IV = Gas rate of production (cu ft per hr)
HV = Heating Value as analyzed (BTU/cu ft)
IGT = Gas temperature (Degrees C)
VC = Volume corrected for temperature compensation
= measured volume X 300/(273+IGT) (BTU/cu ft)
This is to convert the gas volume to volume at NTP
HC = Heat content of gas
= VC X HV (BTU/hr)
HP = IP(KW) X 3413 (BTU/KWhr)
= 3413 IP BTU/hr
HF = Heating value of fuel used (BTU)
HS = Heat utilized to produce the steam used (BTU)
HPT = Average torch power(KW) X 3413(BTU/KWhr) X Time(Hrs)
cumulative from time = zero to time of reference
HO = Total heat output in gas (cumulative to time of ref)
= Average heat content X time (BTU)

HTI = Total heat input (fuel, torch power, and steam) cumulative to time of reference except for steam

EFF = Efficiency

= HO/(HPT + HF + HS/0.80)

where HF = fuel heat content

HS = Heat required to produce the steam utilized in the process (80% efficiency)

3. Symbol Definitions

LINE or LN refers to the line number in the presentation of the data shown in each of the tables

TIME or TS refers to the time (in minutes) after start-up

S = the sample number (0 indicates no sample taken)

VTC = Vessel temperature (in deg C)

PKW = Power (KW)

AFM = Airflow (scfm)

AP = Air pressure (psig)

PGV = Product gas volume (cu ft per hour)

PGHV = Product gas heating value (BTU/cu ft)

PGTC = Product gas temperature (deg C)

SS = Period of steam utilization

Remainder are the same as defined in the variable definitions.

5. Computer Program

```
      FORTRAN IV G LEVEL

       21                        MAIN                        DATE = 83335          22/0.09

      DIMENSION IT(27,30),IVT(27,30),IP(27,30),IV(27,30),HV(27,30)
     1,IGT(27,30),VC(27,30),HC(27,30),HP(27,30),HT(27,30),HS(25)
     1,HF(25),HPT(27,30),HO(27,30),EFF(27,30),K1(25),HVC(27,30)
     1,HTI(27,30),AT1(30),HV1(30),ISN(27,30),AF(27,30),IAP(27,30)
      READ(5,10) (K1(I),I=1,13)
      READ(5,20) (K1(I),I=14,23)
      DO 35 I=1,23
      READ(5,40) HF(I),HS(I)
   40 FORMAT(F7.0,F8.4)
   35 CONTINUE
      CALL PLOTS(21.0,25.0,27.5)
      CALL PLOT(2.0,2.0,-3)
   10 FORMAT(13I2)
   20 FORMAT(10I2)
      DO 100 J=1,23
      K=K1(J)
      DO 200 I=1,K
      READ(5,150) IT(J,I),IVT(J,I),IP(J,I),IV(J,I),HV(J,I),IGT(J,I)
     1,ISN(J,I),AF(J,I),IAP(J,I)
      VC(J,I)=IV(J,I)*303.0/(273.0+IGT(J,I))
      HC(J,I)=HV(J,I)*VC(J,I)
      HP(J,I)=IP(J,I)*3413.0
  150 FORMAT(I2,2X,I3,2X,I3,2X,I4,2X,F6.2,2X,I2,2X,I1,2X,F3.1,2X,I2)
  200 CONTINUE
  100 CONTINUE
      DO 300 J=1,23
      DO 32 IJ=1,30
      AT1(IJ)=0
      HV1(IJ)=0.0
   32 CONTINUE
      K=K1(J)-1
      IK=K+1
      DO 55 I=1,IK
      AT1(I)=IT(J,I)
      HV1(I)=HV(J,I)
   55 CONTINUE
      HPT(J,1)=0.0
      HO(J,1)=0.0
      EFF(J,1)=0.0
      DO 400 I=1,K
      II=I+1
      HPT(J,II)=HPT(J,I)+(HP(J,I)+HP(J,II))*(IT(J,II)-IT(J,I))/120.
      HO(J,II)=HO(J,I)+(HC(J,I)+HC(J,II))*(IT(J,II)-IT(J,I))/120.
      HT1(J,II)=HPT(J,II)+HF(J)+HS(J)/0.8
      EFF(J,II)=HO(J,II)/HT1(J,II)
  400 CONTINUE
      X=1.5
      DO 210 I=1,10
      CALL PLOT(X-1.5,0.0,3)
      CALL PLOT(X     ,0.0,2)
      CALL PLOT(X     ,-0.1,2)
      FPN=FLOAT(I)*10.0
      CALL NUMBER(X-.02,-0.5,.20,FPN,0.0,-1)
  210 X=X+1.5
      CALL SYMBOL(3.0,-1.5,.35,15HTIME IN MINUTES,0.0,15)
      Y=0.0
      DO 220 I=1,17
      CALL PLOT(0.0,Y,3)
      Y=Y+1.1
      CALL PLOT(0.0,Y,2)
      CALL PLOT(-.2,Y,2)
  220 CALL NUMBER(-.30,Y-.04,0.20,20.0*Y/1.1,90.0,1)
```

```
      21                    MAIN                    DATE = 83335          22/.8/
     CALL SYMBOL(-.8,3.0,0.35,27HHEATING VALUE (BTU PER SCF),90
    1.0,27)
     AT1(IK+1)=0.0
     HV1(IK+1)=0.0
     AT1(IK+2)=6.66
     HV1(IK+2)=10.10
     CALL LINE(AT1,HV1,IK,1,1,4)
     CALL SYMBOL(4.0,17.0,0.5,5HRUN= ,0.0,5)
     VAR=FLOAT(J+20)
     CALL NUMBER(999.0,999.0,0.5,VAR,0.0,-1)
     CALL SYMBOL(4.0,16.0,0.35,19HGAS QUALITY VS TIME,0.0,19)
     CALL PLOT(0.0,18.7,3)
     CALL PLOT(0.0,22.0,2)
     CALL PLOT(15.0,22.0,2)
     CALL PLOT(15.0,0.0,2)
     CALL PLOT(22.0,0.0,-3)
300  CONTINUE
     DO 670 J=1,23
     IU=J+20
     WRITE(6,80) IU
 80  FORMAT(1H1,'1',////////,30X,'RUN  =',I3,/)
     WRITE(6,96)
 96  FORMAT(///,2X,'LN  TS  S  VTC  PHW  AFR  AP  EGV  PGHV  PGTC  SS
    1/)
     K=K1(J)
     DO 690 I=1,K
     WRITE(6,86) I,IT(J,I),ISA(J,I),IVT(J,I),IP(J,I),AF(J,I)
    1,IAP(J,I),IV(J,I),MV(J,I),IGT(J,I)
 86  FORMAT(2X,I2,2X,I2,2X,I1,2X,I3,2X,I3,2X,F3.1,2X,I2,2X,
    1I4,2X,F6.1,2X,I2)
690  CONTINUE
     WRITE(6,95)
 95  FORMAT(///////2X,'LINE    TIME      VC          PC          PPT
    1 HO          HTI        EFF'/)
     K=K1(J)
     DO 680 I=1,K
     WRITE(6,85) I,IT(J,I),VC(J,I),PC(J,I),PPT(J,I),PC(J,I)
    1 ,HTI(J,I),EFF(J,I)
 85  FORMAT(3X,I2,3X,I3,3X,F8.3,3X,F9.1,3X,F8.1,3X,F9.1
    1 ,3X,F9.1,3X,F5.3)
680  CONTINUE
670  CONTINUE
     CALL PLOT(0.0,0.0,999)
     STOP
     END
```

4. Printout Tables

RUN = 21

LN	TS	S	VTC	PAR	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	700	120	6.3	50	8600	152.5	55	
2	3	1	700	120	6.1	50	8000	152.5	65	
3	8	2	720	124	6.1	50	8400	150.4	65	
4	13	3	730	121	6.1	50	7900	190.9	65	
5	20	4	735	124	6.0	50	7800	231.4	64	
6	30	5	750	121	6.1	50	3500	204.8	63	
7	37	6	770	120	6.1	50	2200	185.8	60	
8	43	7	780	121	6.0	50	1800	147.7	56	
9	50	8	825	121	6.0	50	1700	109.6	56	
10	50	0	825	0	6.0	50	1700	109.8	56	
11	60	0	825	0	5.6	40	1200	109.6	56	

LINE	TIME	VC	PC	MPT	MC	MTI	EFF
1	0	7317.070	1115388.0	0.0	0.0	0.0	0.0
2	3	7106.580	1082881.0	20478.6	54874.5	568678.0	0.097
3	8	7455.621	1121548.0	55176.8	146828.9	603378.8	0.243
4	13	7011.832	1338628.0	80017.8	240337.3	638217.8	0.391
5	20	6843.617	1606614.0	138795.3	421142.9	686985.3	0.613
6	30	3125.000	630843.8	208477.3	608347.6	756677.3	0.804
7	37	1881.884	360272.0	256458.4	887154.3	804658.4	0.828
8	43	1732.523	259828.2	297585.8	698384.3	845785.8	0.826
9	50	1590.152	169827.8	345765.1	723265.9	893965.1	0.808
10	50	1590.152	169827.8	345765.1	723265.9	893965.1	0.808
11	60	1094.225	119848.8	345765.1	747382.3	893965.1	0.838

RUN = 22

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGMV	PGTC	SS
1	0	0	790	128	5.6	40	8800	262.8	56	
2	3	1	790	128	5.4	40	8800	262.8	55	
3	7	2	800	137	5.4	40	8000	228.5	60	
4	13	3	810	133	5.3	40	7800	228.0	65	
5	20	4	820	133	5.3	40	6600	150.5	65	
6	30	5	825	130	5.3	40	3200	213.7	63	
7	35	6	845	126	5.3	40	2800	166.6	60	
8	40	7	865	130	5.3	40	2200	118.5	53	
9	50	8	880	130	5.3	40	1800	145.0	52	
10	50	0	880	0	5.3	40	1800	145.0	52	
11	60	0	880	0	5.3	40	1000	145.0	50	

LINE	TIME	VC	PC	MPT	MG	MTI	EFF
1	0	8173.371	2148814.0	0.0	0.0	0.0	0.0
2	3	8048.777	2118861.0	22013.8	106811.9	570213.8	0.187
3	7	7207.267	1847207.0	92275.8	232347.4	690475.8	0.386
4	13	6745.558	1524631.0	88351.3	380638.3	648551.3	0.634
5	20	5857.984	881909.4	191309.6	530897.4	699508.6	0.748
6	30	2857.143	610599.8	228111.2	655338.8	774311.2	0.848
7	35	2522.822	420327.8	262916.5	698295.1	810716.5	0.861
8	40	2024.540	242013.4	298921.8	729892.6	847121.8	0.857
9	50	1861.538	246908.4	372870.1	788135.8	921070.1	0.832
10	50	1861.538	240808.4	372870.1	764135.9	921070.1	0.832
11	60	928.782	134665.8	372870.1	787433.5	921070.1	0.864

RUN = 23

LN	TS	S	VTC	PKb	APM	AP	PGV	PGMV	PGTC	SS
1	0	0	860	181	6.6	65	9200	255.0	60	
2	2	1	860	181	6.6	65	8000	255.0	62	
3	5	2	870	181	6.7	65	8400	248.1	64	
4	8	3	880	181	6.7	65	8000	241.2	65	
5	13	4	880	181	6.7	65	6600	182.4	65	
6	21	5	880	172	6.7	65	4400	202.1	65	
7	33	6	940	180	6.7	65	2600	191.8	60	
8	45	7	860	181	6.7	65	2200	191.8	55	

LINE	TIME	VC	MC	MPT	MC	MTI	EFF
1	0	8288.285	2113428.0	0.0	0.0	0.0	0.0
2	2	6058.698	2055142.0	20591.8	88476.1	568791.8	0.142
3	5	7477.742	1855302.0	51478.4	167237.2	599678.4	0.278
4	8	7100.580	1712875.0	82367.1	258441.6	630567.1	0.407
5	13	5857.984	1068498.0	133846.4	372332.0	682046.4	0.546
6	21	3805.325	788227.2	214185.7	486180.2	762385.7	0.681
7	33	2342.342	359685.4	334303.3	610692.4	882503.3	0.882
8	45	2012.185	305732.8	457912.5	676859.2	1005712.5	0.673

RUN = 24

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGMV	PGTC	SS
1	0	0	880	172	6.6	60	7200	226.0	55	
2	3	1	880	168	6.3	60	7000	226.0	60	
3	8	2	808	164	6.3	60	6300	235.2	65	
4	18	3	810	168	6.3	80	4200	228.0	65	
5	26	4	920	164	6.0	60	3200	213.0	65	
6	38	5	830	160	6.0	60	2400	130.7	60	
7	41	0	830	160	6.0	80	1800	130.7	55	

LINE	TIME	VC	PC	MPT	MO	MTI	EFF
1	0	8585.363	1488160.0	0.0	0.0	0.0	0.0
2	3	8306.305	1425098.0	29010.5	72831.4	577210.5	0.126
3	8	5581.715	1315115.0	85868.3	209842.1	633868.3	0.331
4	18	3727.811	890089.9	151764.6	336145.6	699864.6	0.486
5	26	2840.237	804870.4	246190.9	457400.6	784390.9	0.576
6	38	2162.182	202816.2	338341.8	531366.1	806541.8	0.569
7	41	1846.341	215183.3	383848.6	552108.1	832048.6	0.592

RUN = 25

LN	TS	S	VTC	PKV	AFM	AP	PGV	PGHV	PGTC	SS
1	0	1	780	121	5.6	45	7000	228.3	57	
2	5	2	780	133	5.4	45	5800	228.3	61	
3	10	3	780	133	5.4	45	5500	212.0	65	
4	18	4	780	133	5.4	45	5000	195.6	66	
5	30	5	780	128	5.4	45	3000	177.7	65	
6	44	6	800	126	5.4	45	2200	133.8	60	
7	72	7	840	126	5.4	45	1600	95.6	55	
8	86	8	860	133	5.4	45	1550	57.5	52	
9	90	0	860	133	5.4	45	1400	57.5	52	

LINE	TIME	VC	MC	MPT	MG	MTI	EFF
1	0	8363.633	1453071.0	0.0	0.0	0.0	0.0
2	5	5028.936	1148535.0	36120.8	108400.3	594320.8	0.108
3	10	4881.656	1034862.3	73848.3	198375.1	622148.3	0.326
4	18	4424.777	885619.1	134472.1	320073.8	682672.1	0.478
5	30	2862.722	473272.1	223882.7	459882.9	772682.7	0.588
6	44	1981.982	265148.5	325429.4	546112.6	873629.4	0.629
7	72	1463.415	138948.3	526113.8	840634.3	1074313.6	0.586
8	86	1430.768	82240.6	628243.3	868556.1	1177443.0	0.564
9	90	1282.308	74281.8	658505.1	871773.4	1207705.0	0.556

RUN = 26

LN	TS	S	VTC	PKb	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	860	105	5.5	40	6200	245.1	59	
2	6	1	860	116	5.4	40	6200	245.1	60	
3	15	2	870	116	5.3	40	4400	234.4	62	
4	25	3	880	116	5.3	40	3800	236.8	65	
5	30	4	880	109	5.3	40	3500	197.4	65	
6	34	5	900	119	5.3	40	3100	241.8	62	
7	53	6	900	118	5.3	40	2000	223.8	60	
8	73	7	910	116	5.3	40	1500	186.3	55	
9	95	8	920	116	5.3	40	1350	186.8	54	

LINE	TIME	VC	PC	HPT	HC	HTI	EFF
1	0	5870.730	1390066.0	0.0	0.0	0.0	0.0
2	6	5585.582	1358193.0	37713.6	137862.9	585813.6	0.235
3	15	3840.288	823802.9	97089.8	308837.4	645288.8	0.486
4	25	3372.781	788180.4	163084.4	453519.3	711284.4	0.638
5	30	3106.509	613255.8	195081.3	512370.8	743281.3	0.689
6	34	2776.119	671682.1	221020.1	555261.9	769220.1	0.722
7	53	1801.802	403315.3	348633.3	725469.8	897833.3	0.808
8	73	1371.851	220196.6	483308.1	830661.6	1031508.1	0.805
9	95	1238.532	134777.0	628475.3	897206.7	1176675.0	0.762

RUN = 27

LN	TS	S	VTC	PKW	AFW	AP	PGV	PGHV	PGTC	SS
1	0	0	860	106	5.3	37	6600	212.0	55	
2	1	1	860	121	5.2	37	6600	212.0	55	
3	8	2	880	125	5.2	37	3500	207.3	58	
4	14	3	890	124	5.1	37	3400	163.2	60	
5	18	4	900	125	5.1	37	3200	118.5	62	
6	28	5	910	128	5.1	37	2800	110.5	62	
7	40	6	920	128	5.1	37	2000	130.2	55	
8	60	7	940	128	5.1	37	1600	148.8	52	
9	72	8	950	122	5.1	37	1200	167.0	50	
10	75	0	950	122	5.1	37	1200	167.0	50	

LINE	TIME	VC	PC	MPT	MC	MTI	EFF
1	0	6036.582	1276896.0	0.0	0.0	0.0	0.0
2	1	6036.582	1276896.0	8456.3	21333.3	373750.3	0.057
3	8	3172.205	658327.8	41439.5	102086.7	408733.5	0.250
4	14	3063.063	488768.3	88085.3	178303.1	465389.3	0.385
5	18	2865.872	338467.4	133505.1	214271.3	500798.1	0.428
6	28	2507.463	277188.8	198522.8	260521.3	565816.8	0.460
7	40	1828.268	238207.3	286578.1	312062.0	653872.1	0.477
8	60	1476.823	221375.8	433337.0	388858.2	800831.0	0.485
9	72	1114.551	186118.8	518003.3	429408.8	886297.3	0.484
10	75	1114.551	186118.8	538822.5	438714.5	907116.5	0.484

RUN = 28

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	680	116	5.5	45	6800	250.6	55	
2	1	1	880	121	5.4	45	6800	250.6	55	
3	5	2	880	128	5.4	45	4200	250.6	55	
4	11	3	880	128	5.4	45	4000	194.1	58	
5	21	4	880	137	5.4	45	3200	166.0	58	
6	30	5	885	128	5.4	45	2500	218.2	58	
7	45	6	905	133	5.4	45	1700	198.1	55	
8	58	7	920	133	5.4	45	1400	179.8	52	
9	64	0	920	133	5.4	45	1200	179.9	52	

LINE	TIME	VC	PC	HPT	HC	HTI	EFF
1	0	6219.512	1558858.0	0.0	0.0	0.0	0.0
2	1	6219.512	1558858.0	6740.7	25981.0	364185.6	0.071
3	5	3841.463	862824.4	35182.3	110037.0	392627.3	0.280
4	11	3625.377	703830.8	79210.0	193369.8	436655.0	0.443
5	21	2900.302	481537.1	154864.8	292150.3	512368.8	0.570
6	30	2278.635	497507.6	222954.1	365578.6	580398.1	0.636
7	45	1554.878	309545.1	334728.9	466460.2	692174.9	0.674
8	56	1282.308	232498.0	417950.2	516147.5	775395.2	0.696
9	64	1107.692	199284.9	478474.0	544933.1	835919.0	0.652

RUN = 28

LN	TS	S	VTC	PKb	AFM	AP	FGV	PGHV	PGTC	SS
1	0	0	880	144	6.4	60	9400	183.9	64	
2	3	1	880	147	6.2	60	9400	183.9	65	
3	6	2	880	144	6.1	60	6200	236.8	65	
4	10	3	880	151	6.1	60	5600	191.4	65	
5	17	4	880	151	6.1	60	3800	146.0	65	
6	28	5	890	146	6.1	60	2800	115.4	60	
7	40	6	920	145	6.1	60	2400	105.2	55	
8	50	7	940	144	6.1	60	2200	80.6	52	
9	70	8	999	141	6.1	60	2000	29.5	50	
10	70	0	999	0	6.1	60	2000	29.5	50	
11	80	0	888	0	6.1	60	1900	29.5	50	

LINE	TIME	VC	FC	HPT	HC	HTI	EFF
1	0	8367.948	1539200.0	0.0	0.0	0.0	0.0
2	3	8343.191	1534646.0	24829.6	76846.1	550329.6	0.138
3	6	5502.957	1303375.0	49659.1	147796.8	583159.1	0.253
4	10	4970.414	951536.0	83220.3	222960.3	616720.3	0.362
5	17	3372.781	492493.4	143345.9	307185.3	676845.9	0.454
6	28	2522.522	291089.1	236264.8	378024.0	769764.8	0.492
7	40	2195.122	230860.9	335583.1	431220.6	869083.1	0.496
8	50	2030.769	163598.7	417779.4	464092.2	951279.4	0.488
9	70	1857.585	54817.3	579896.9	500494.8	1113396.0	0.450
10	70	1857.585	54817.3	579896.9	500494.8	1113396.0	0.450
11	80	1764.706	52076.5	579896.9	509402.6	1113396.0	0.458

RUN = 30

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	880	151	6.5	65	9000	231.1	55	
2	3	1	880	146	6.3	65	9000	231.1	65	
3	8	2	880	150	6.3	65	5000	213.0	65	
4	14	3	880	154	6.3	65	3800	140.6	65	
5	22	4	915	154	6.3	65	2200	101.1	69	
6	30	5	945	154	6.3	65	2000	72.1	65	
7	35	6	970	150	6.3	65	1900	57.8	55	
8	45	7	990	154	6.3	65	1700	14.6	50	
9	45	0	990	0	6.3	65	1700	14.6	50	
10	60	8	990	0	6.3	65	1700	8.5	50	

LINE	TIME	VC	MC	MPT	MD	MTI	EFF
1	0	8231.707	1902100.0	0.0	0.0	0.0	0.0
2	3	7988.164	1845825.0	25341.5	93698.1	323893.5	0.288
3	8	4437.867	945310.1	67435.2	209995.4	365887.2	0.574
4	14	3195.266	449286.3	119312.8	279725.1	417864.8	0.669
5	22	1952.663	197453.2	189393.0	322841.1	487945.0	0.662
6	30	1775.148	127970.4	259473.3	344535.9	558025.3	0.617
7	35	1737.805	100497.2	302704.6	354055.4	601256.6	0.589
8	45	1578.947	22989.5	389167.2	364345.9	687719.2	0.530
9	45	1578.947	22989.5	389167.2	364345.9	687719.2	0.530
10	60	1578.947	10342.1	389167.2	368512.3	687719.2	0.536

RUN = 31

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	870	152	6.2	55	9200	233.1	55	
2	2	1	870	152	6.1	55	9200	233.1	65	
3	7	2	880	159	6.1	55	7000	218.4	65	
4	15	3	880	155	6.1	55	6000	223.3	65	
5	24	4	880	143	6.1	55	3800	178.0	62	
6	35	5	910	143	6.1	55	2800	132.8	62	
7	45	6	955	142	6.1	55	2400	110.0	60	
8	55	7	870	141	6.1	55	2000	96.3	58	
9	65	8	999	142	6.1	55	1800	43.3	56	
10	85	0	999	0	6.1	55	1800	43.3	56	
11	77	0	999	0	6.1	55	1700	43.3	56	

LINE	TIME	VC	MC	MPT	MO	MTI	EFF
1	0	8414.833	1861534.0	0.0	0.0	0.0	0.0
2	2	8165.680	1803501.0	17292.5	64417.3	472892.5	0.136
3	7	6213.016	1357108.0	61519.3	200275.9	517119.3	0.387
4	15	5325.441	1188958.0	132964.8	370013.6	588564.8	0.629
5	24	3402.985	605867.4	208245.3	504825.5	664845.3	0.759
6	35	2907.483	333041.1	298722.7	590892.1	754322.7	0.783
7	45	2182.182	237924.3	378781.4	638272.5	835381.4	0.764
8	55	1812.689	174471.3	460271.3	672838.8	915871.3	0.734
9	65	1841.337	71086.3	540761.2	693101.9	996361.2	0.696
10	85	1841.337	71086.3	540761.2	693101.9	996361.2	0.696
11	77	1550.152	67137.1	540761.2	706924.2	996361.2	0.710

RUN = 32

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	680	137	5.8	50	6000	228.3	50	
2	1	1	690	137	5.7	50	5400	228.3	55	
3	5	2	700	133	5.6	50	4000	228.3	60	
4	10	3	710	137	5.8	50	3200	212.0	62	
5	19	4	720	129	5.6	50	2200	195.6	63	
6	24	5	730	137	5.8	50	2000	177.7	63	
7	28	6	740	129	5.6	50	2000	133.8	63	
8	44	7	765	130	5.6	50	1600	95.6	60	
9	49	8	825	133	5.6	50	1400	57.5	55	
10	56	0	825	133	5.6	50	1400	57.5	55	

LINE	TIME	VC	MC	MPT	MD	MTI	EFF
1	0	5572.754	1272482.0	0.0	0.0	0.0	0.0
2	1	4939.023	1127776.0	7783.0	20062.1	375087.0	0.053
3	5	3603.604	822848.8	38510.0	85022.9	405804.0	0.210
4	10	2865.672	607493.7	76906.3	144620.4	444200.0	0.326
5	19	1964.286	384273.1	144885.6	219062.9	512289.6	0.427
6	24	1785.714	317392.8	182822.9	248238.9	550116.9	0.451
7	28	1785.714	238892.8	213084.8	266781.8	580378.8	0.460
8	44	1441.441	137845.0	330847.1	317013.4	698241.1	0.454
9	49	1280.488	73602.4	368347.8	325823.7	735641.8	0.443
10	56	1280.488	73602.4	421308.2	334410.6	788600.2	0.424

RUN = 33

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGMV	PGTC	SS
1	0	0	760	118	5.8	50	7200	245.3	50	
2	1	1	760	122	5.8	50	7000	245.3	52	
3	4	2	760	130	5.8	50	5600	243.8	60	
4	8	3	770	126	5.8	50	4800	242.0	61	
5	14	4	770	137	5.8	50	3700	226.8	63	
6	20	5	760	133	5.8	50	2900	211.6	62	
7	28	6	800	137	5.8	50	1800	158.6	60	
8	40	7	830	133	5.8	50	1500	105.8	55	
9	60	8	850	133	5.8	50	1400	94.7	56	
10	65	0	880	137	5.8	50	1400	94.7	50	

LINE	TIME	VC	MC	MPT	MG	MTI	EFF
1	0	8687.305	1640128.0	0.0	0.0	0.0	0.0
2	1	8461.535	1584756.0	6826.0	26874.0	374120.0	0.072
3	4	9049.043	1228224.0	28327.9	97223.9	395621.9	0.246
4	8	4311.375	1043525.1	57452.2	172981.8	424746.1	0.407
5	14	3303.571	748348.0	102333.1	262625.4	469627.1	0.559
6	20	2587.015	549554.3	148408.6	327570.6	515702.6	0.635
7	28	1821.822	257189.1	209842.6	381353.4	577136.6	0.661
8	40	1371.851	144864.3	301993.6	421558.8	669287.6	0.630
9	60	1300.310	123139.3	453303.1	466226.0	820597.1	0.568
10	65	1300.310	123138.3	481689.4	476487.6	858993.4	0.555

RUN = 34

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	870	152	5.5	45	9999	246.0	55	
2	3	1	870	152	5.4	45	9999	246.0	64	
3	8	2	870	152	5.3	45	9200	239.8	65	
4	13	3	870	148	5.3	45	8000	240.8	65	
5	15	0	870	148	5.3	45	8000	187.4	65	
6	20	4	880	148	5.2	45	9000	187.4	65	
7	25	5	890	152	5.2	45	8000	134.1	65	
8	27	0	895	152	5.2	45	3600	158.4	66	
9	30	6	900	152	5.2	45	9400	184.7	67	
10	37	0	905	150	5.2	45	9400	98.2	69	
11	43	0	905	150	5.2	45	2000	98.2	70	
12	46	7	910	148	5.2	45	5400	7.6	70	
13	48	0	815	143	5.2	45	3000	7.6	70	
14	60	0	840	143	5.2	45	2000	7.6	70	

LINE	TIME	VC	MC	MPT	MC	MTI	EFF
1	0	9145.426	2248957.0	0.0	0.0	0.0	0.0
2	3	8901.184	2188869.0	25938.8	140995.6	615938.8	0.180
3	8	8165.680	1958374.0	69170.1	283838.9	659170.1	0.431
4	13	7100.590	1708756.0	111832.6	436636.0	701832.8	0.622
5	15	5325.441	897881.1	128870.1	481746.6	718870.1	0.670
6	20	7988.164	1496822.0	170763.7	585682.5	760763.7	0.770
7	25	7988.164	1071212.0	213426.2	692693.9	803426.2	0.862
8	27	3195.841	507854.8	230718.7	719011.6	820718.7	0.876
9	30	8294.117	1532089.0	256657.4	770010.2	846657.4	0.909
10	37	8245.813	792898.1	316783.1	805634.4	906783.1	0.955
11	43	1748.271	168209.9	367978.1	953689.8	957978.1	0.996
12	46	4723.031	35847.8	393404.9	958791.2	983404.9	0.975
13	48	2623.806	18915.4	418234.4	960189.3	1008234.4	0.952
14	60	1748.271	13277.0	507711.9	963227.9	1097711.0	0.877

RUN = 35

LN	TS	S	VTC	PKφ	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	860	156	6.5	65	9999	136.6	55	
2	1	1	860	156	6.3	65	9999	136.6	55	
3	6	2	880	158	6.3	65	8800	227.1	60	
4	11	0	860	153	6.3	65	7400	195.5	63	
5	15	3	860	150	6.3	65	9999	183.8	65	
6	21	4	860	148	6.3	65	9999	178.5	66	
7	26	0	860	150	6.3	65	9000	155.0	66	
8	30	5	860	152	6.3	65	8999	133.4	67	
9	38	6	900	152	6.3	65	9999	57.5	70	
10	40	0	900	152	6.3	65	8000	52.8	70	
11	50	0	920	152	6.2	65	2100	52.8	70	
12	54	7	840	154	6.2	65	9999	48.1	70	
13	56	0	860	148	6.2	65	1700	26.3	66	
14	66	8	860	148	6.2	65	1800	4.5	55	

LINE	TIME	VC	FC	HPT	HC	HTI	EFF
1	0	9145.426	1249722.0	0.0	0.0	0.0	0.0
2	1	9145.426	1249722.0	8873.8	20828.7	632865.0	0.033
3	6	7827.826	1800869.0	53242.8	147928.3	877234.0	0.218
4	11	8807.141	1281431.0	97185.1	276765.8	721176.4	0.384
5	15	8874.852	1453811.0	131656.4	368267.2	755647.6	0.487
6	21	8848.872	1562144.0	182510.1	518054.9	806501.3	0.644
7	28	7864.862	1234433.0	224888.1	635578.9	848879.4	0.749
8	30	8822.645	1177205.0	259245.8	715966.8	883236.9	0.811
9	38	8745.480	502515.2	328413.8	827848.1	952407.0	0.869
10	40	8887.082	369515.9	345708.3	842481.9	869699.5	0.868
11	50	1836.735	86887.8	432179.8	881358.6	1056162.0	0.834
12	54	8745.480	421084.8	486755.8	898627.8	1090747.0	0.824
13	56	1531.531	40309.8	483820.9	906317.8	1107812.0	0.818
14	66	1646.341	7392.1	566008.3	810292.9	1191898.0	0.764

RUN = 36

LN	TS	S	VTC	PK#	AFP	AP	PGV	PGHV	PGTC	SS
1	0	0	880	144	5.4	37	6200	271.4	60	
2	8	1	880	144	5.3	37	8000	271.4	79	
3	10	0	880	142	5.3	37	6800	248.4	77	
4	15	2	880	140	5.3	37	8888	225.3	80	
5	23	3	880	137	5.3	37	8888	174.9	80	
6	25	0	885	137	5.3	37	9000	193.2	80	
7	30	4	900	137	5.3	37	4000	211.5	60	
8	35	0	900	136	5.3	37	3000	184.5	82	
9	40	5	900	135	5.3	37	8500	157.5	84	
10	45	6	910	137	5.2	37	8300	150.4	86	
11	50	0	915	136	5.2	37	8600	123.8	86	
12	53	7	920	135	5.2	37	2200	97.1	86	
13	57	0	935	135	5.2	37	2000	97.1	86	
14	70	8	950	135	5.2	37	1900	97.1	86	

LINE	TIME	VC	PC	MPT	MC	PTI	EFF
1	0	7387.387	2005157.0	0.0	0.0	0.0	0.0
2	8	6886.551	1871830.0	48147.2	193854.3	697253.4	0.278
3	10	5828.570	1447758.0	81684.4	304510.5	729790.7	0.417
4	15	8487.730	1914878.0	121787.2	444820.2	769853.4	0.578
5	23	8487.730	1486677.0	184813.9	671390.4	832920.1	0.806
6	25	7848.723	1477886.0	200399.9	720789.8	848506.1	0.848
7	30	3388.433	718946.1	238364.9	812334.4	887471.2	0.915
8	35	2535.211	467771.8	278187.8	861780.9	926294.1	0.930
9	40	7142.855	1125214.0	318726.3	928155.3	964832.5	0.962
10	45	8935.930	1043371.8	355408.9	1018513.0	1003513.1	1.018
11	50	7146.629	889560.8	394229.8	1098051.0	1042336.0	1.054
12	53	1838.440	178567.6	417352.8	1125754.0	1065459.0	1.057
13	57	1871.309	162334.2	448069.8	1137117.0	1096176.0	1.037
14	70	1567.744	154217.5	547900.1	1171410.0	1196006.0	0.979

RUN = 37

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGMV	PGTC	SS
1	0	0	860	116	5.2	35	8000	250.1	60	
2	3	1	865	116	5.1	35	8000	250.1	65	
3	7	2	870	116	5.1	35	6200	245.0	68	
4	12	0	875	116	5.0	35	9999	222.5	71	
5	15	3	880	116	5.0	35	9999	200.1	74	
6	21	4	890	116	5.0	35	9800	201.8	82	
7	23	0	890	116	5.0	35	3600	191.2	80	
8	25	0	890	116	5.2	38	4000	191.2	78	
9	33	5	890	116	5.1	38	2800	180.6	76	
10	35	0	890	116	5.1	38	9999	174.0	85	
11	41	6	900	112	5.1	38	5800	167.5	85	
12	44	7	900	112	5.1	38	8400	154.2	85	
13	51	0	905	110	5.1	38	6800	151.8	78	
14	60	8	910	108	5.1	38	1800	149.3	70	
15	65	0	910	108	5.1	38	1000	148.3	70	

LINE	TIME	VC	PC	MPT	MC	MTI	EFF
1	0	7207.207	1802450.0	0.0	0.0	0.0	0.0
2	3	7100.580	1775788.0	18795.4	88455.9	453694.4	0.197
3	7	5454.543	1338189.0	46189.3	193188.7	480088.3	0.402
4	12	8720.055	1840473.0	79181.6	328716.7	513080.6	0.643
5	15	8644.668	1728711.0	98976.9	421471.3	532875.9	0.791
6	21	8366.195	1888800.0	138567.7	582396.7	572466.7	1.035
7	23	3058.496	585035.8	151764.6	630283.8	585663.6	1.076
8	25	3418.803	653743.5	164961.4	650940.3	598860.4	1.087
9	33	2406.877	424633.8	217748.4	723498.7	651648.2	1.110
10	35	8378.047	1458373.0	230946.0	755048.8	664845.0	1.136
11	41	4860.332	814202.8	269854.2	868877.5	703753.2	1.234
12	44	7038.105	1085218.0	288866.8	916163.0	722865.8	1.267
13	51	7921.387	1141442.0	333185.3	1048051.5	767064.3	1.364
14	60	1574.344	235112.5	388987.8	1149293.0	822866.8	1.397
15	65	874.635	130618.0	419684.8	1184531.0	853583.8	1.364

RUN = 38

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	680	148	6.3	55	6500	215.0	57	
2	5	1	680	158	6.2	55	8700	215.0	66	
3	7	0	685	153	6.2	55	8000	208.0	65	
4	12	2	690	148	6.2	55	9800	200.8	77	
5	17	3	690	153	6.2	55	9899	180.6	77	
6	22	4	710	150	6.1	55	9999	141.0	77	
7	27	5	720	156	6.1	55	8600	126.1	77	
8	32	6	740	154	6.1	55	5600	80.7	78	
9	37	7	760	155	6.1	55	9400	110.0	73	
10	51	8	780	154	6.1	55	9500	74.4	70	
11	60	9	810	152	6.1	55	1600	4.8	68	
12	62	0	810	152	6.1	55	1600	4.8	68	

LINE	TIME	VC	MC	MPT	MC	MTI	EFF
1	0	7727.270	1681440.0	0.0	0.0	0.0	0.0
2	5	7837.836	1685213.0	43373.5	139443.9	547206.3	0.255
3	7	7100.580	1476709.0	60950.5	182142.6	564783.2	0.340
4	12	8400.000	1687727.0	103887.4	323984.1	607730.1	0.533
5	17	8570.570	1547759.0	146844.3	458805.9	650677.0	0.705
6	22	8570.570	1208364.0	189833.4	573644.4	693766.1	0.827
7	27	8228.570	1037375.8	233449.1	667216.8	737281.9	0.905
8	32	4788.324	386208.4	277533.7	726532.8	781366.4	0.930
9	37	8150.285	886205.3	321476.1	779866.7	825308.8	0.945
10	51	8308.035	617942.8	444514.7	956817.2	948347.4	1.009
11	60	1407.625	8798.8	522843.0	1003472.8	1026675.8	0.977
12	62	1407.625	8798.8	540135.5	1003699.4	1043968.3	0.961

RUN = 39

LN	TS	S	VTC	PKb	AFM	AP	PGV	PGMV	PGTC	SS
1	0	0	780	155	5.6	45	9000	248.2	60	
2	3	1	780	151	5.5	45	7800	248.2	70	
3	5	0	780	150	5.4	45	8999	232.6	74	
4	11	2	780	148	5.4	45	8000	217.1	78	
5	16	3	790	146	5.4	45	9000	197.0	78	
6	21	4	800	146	5.4	45	8200	142.8	75	
7	26	3	810	144	5.4	45	9400	147.9	75	
8	32	5	820	142	5.4	45	2200	153.0	70	
9	36	0	830	142	5.4	45	8999	144.4	70	
10	38	6	840	142	5.4	45	7400	135.8	70	
11	44	7	860	140	5.4	45	2000	103.1	70	
12	60	8	890	137	5.4	45	1600	65.5	70	
13	63	0	890	137	5.4	45	1600	65.5	70	

LINE	TIME	VC	MC	MPT	MD	MTI	EFF
1	0	8108.109	2012107.0	0.0	0.0	0.0	0.0
2	3	8822.158	1892888.0	26109.4	82627.3	473328.4	0.498
3	5	8844.668	2010822.0	43231.3	154359.1	490450.3	0.315
4	11	8837.609	1484307.0	94085.0	329120.4	541304.0	0.608
5	16	7882.305	1515230.0	139884.3	454101.1	583113.3	0.778
6	21	7931.031	1132951.0	177419.1	564425.3	624638.1	0.904
7	26	8103.445	1108661.0	218658.4	661558.1	665878.4	0.994
8	32	1824.198	294478.3	267485.3	736218.1	714684.3	1.030
9	36	8749.480	1262834.0	288775.0	788129.8	746994.0	1.055
10	38	6472.331	878808.9	324007.3	841873.3	771226.3	1.091
11	44	1749.271	180419.8	364110.0	885807.8	811329.0	1.092
12	60	1388.417	81703.8	490163.4	922080.9	937382.4	0.984
13	63	1388.417	81703.8	513542.4	926876.1	960761.4	0.965

RUN = 40

LN	TS	S	VTC	PKe	AFM	AP	PCV	PGHV	PGTC	SS
1	0	0	870	132	5.5	45	8600	256.7	50	
2	3	1	870	132	5.4	45	5200	256.7	53	
3	7	2	870	130	5.4	45	4400	255.5	57	
4	10	3	875	124	5.4	45	8800	228.6	65	
5	13	3	880	124	5.4	45	7700	203.8	72	
6	18	4	880	126	5.4	45	8500	196.8	75	
7	21	0	880	131	5.4	50	6998	178.2	77	
8	28	5	900	136	5.4	50	8200	161.7	80	
9	30	0	900	136	5.4	50	8000	164.3	84	
10	40	6	915	138	5.3	50	2600	166.9	76	
11	45	0	925	138	5.3	50	2200	163.3	75	
12	53	7	940	138	5.3	50	8200	158.7	63	
13	60	8	950	138	5.3	50	7200	169.4	87	
14	62	0	950	132	5.3	50	6400	137.1	87	
15	65	0	950	132	5.3	55	7200	137.1	87	
16	68	0	960	132	5.2	55	2800	137.1	84	
17	75	9	870	134	5.3	55	2200	98.8	80	
18	75	0	870	0	5.3	55	2200	98.8	80	
19	85	0	870	0	5.4	55	2200	98.8	80	

LINE	TIME	VC	PC	MPT	MC	MTI	EFF
1	0	7430.340	1907581.0	0.0	0.0	0.0	0.0
2	3	4765.273	1228523.0	22925.8	78402.8	689234.5	0.114
3	7	4000.000	1022000.0	52332.7	153420.2	719041.4	0.213
4	10	6698.223	1997546.0	74005.2	228908.6	740713.8	0.305
5	13	8885.648	1384573.0	95165.8	312981.8	761874.5	0.411
6	18	8189.652	1610249.0	137828.3	461702.8	804537.0	0.574
7	21	8570.570	1535589.0	152447.3	514133.4	819196.0	0.628
8	28	6968.836	1126930.0	205604.7	669447.0	872313.4	0.767
9	30	8722.688	1104738.0	221078.9	706641.4	887785.7	0.796
10	40	2234.857	373103.6	298438.3	829794.9	965147.0	0.860
11	45	1898.552	309782.7	337403.3	858248.5	1004112.1	0.855
12	53	6910.109	1103820.0	389747.4	952488.6	1068456.0	0.893
13	60	6000.000	1016399.9	454298.5	1076168.0	1121007.0	0.960
14	62	5333.332	731413.1	469657.0	1105298.0	1136365.0	0.973
15	65	6000.000	822838.8	482182.8	1144154.0	1158891.0	0.987
16	68	2184.874	299633.6	514708.5	1172215.0	1181417.0	0.992
17	75	1869.688	184856.1	567666.9	1200476.0	1234374.0	0.973
18	75	1869.688	184856.1	567666.9	1200476.0	1234374.0	0.973
19	85	1869.688	184856.1	567666.9	1231285.0	1234374.0	0.997

RUN = 41

LN	TS	S	VTC	PKe	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	860	126	6.2	50	8895	197.5	50	
2	5	1	860	132	6.1	50	8600	197.5	56	
3	10	2	860	130	6.0	50	6600	193.5	62	
4	15	0	865	130	6.0	50	3000	206.8	66	
5	22	3	870	128	6.0	50	8800	220.3	70	
6	30	4	870	136	6.1	55	8800	208.3	78	
7	35	0	880	136	6.1	55	3600	196.3	78	
8	40	5	890	138	6.0	55	3000	111.9	72	
9	45	0	900	136	6.0	55	2400	150.1	70	
10	50	6	905	136	6.0	55	8200	188.2	78	
11	58	7	920	136	6.1	55	8400	141.3	84	
12	80	0	920	136	6.0	55	7200	107.7	86	
13	69	8	930	132	6.1	55	2300	74.1	80	
14	75	0	850	132	6.0	55	2100	74.1	75	

LINE	TIME	VC	PC	HFT	HC
1	0	8288.896	1633985.0	0.0	0.0
2	5	7841.841	1548628.0	36689.8	140942.5
3	10	5810.445	1143434.0	73948.3	253111.6
4	15	2654.867	548318.5	110822.4	323842.8
5	22	7696.793	1695988.0	162288.1	454619.1
6	30	7350.426	1531314.0	224356.8	668772.5
7	35	3076.923	603998.9	261037.4	758743.9
8	40	2608.696	291834.8	300002.5	796070.3
9	45	2088.125	314994.7	338987.6	821354.8
10	50	7008.547	1319288.0	377648.2	889449.9
11	58	7058.820	887693.8	424084.9	1005284.9
12	80	6018.711	648180.2	455008.4	1080161.0
13	65	1854.674	144860.8	493121.3	1093204.0
14	75	1810.345	134164.8	568207.3	1116456.0

RUN = 42

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	870	112	5.4	42	7000	211.4	72	
2	5	1	875	112	5.3	42	6100	211.4	76	
3	10	2	880	112	5.3	42	5600	227.8	80	
4	15	0	890	108	5.2	42	9200	201.6	82	
5	23	3	900	104	5.2	42	7700	175.5	85	
6	32	4	910	100	5.2	42	9800	147.4	88	
7	33	0	910	100	5.2	42	3800	159.4	84	
8	42	5	910	100	5.2	42	3300	171.8	80	
9	45	0	912	100	5.1	42	9000	147.3	85	
10	51	6	915	100	5.1	42	8100	122.8	90	
11	58	7	915	92	5.1	42	9400	80.1	90	
12	60	0	915	92	5.1	42	3000	68.3	90	
13	65	8	915	92	5.1	42	1800	58.4	90	
14	65	0	915	0	5.1	42	1800	56.4	90	
15	75	0	915	0	5.2	42	1700	58.4	90	

LINE	TIME	VC	HC	HPT	HO	HTI	EFF
1	0	6086.853	1286964.0	0.0	0.0	0.0	0.0
2	5	5243.551	1108643.0	31854.7	99816.9	440304.1	0.227
3	10	4759.203	1084098.0	63709.3	191181.1	472158.8	0.405
4	15	7774.645	1567878.0	94895.1	301871.8	503444.6	0.599
5	23	6452.512	1132286.0	143232.2	481669.4	551681.7	0.873
6	32	8144.043	1206838.0	195451.1	656853.6	603900.6	1.087
7	33	3283.277	508168.0	201139.4	670903.6	609588.9	1.101
8	42	2804.532	481734.5	252334.4	745221.3	660783.9	1.128
9	45	7541.888	1110997.0	269399.4	785039.5	677848.9	1.158
10	51	7520.660	923913.0	303529.4	886765.0	711978.9	1.246
11	58	7768.594	622497.3	341754.8	976982.3	750204.4	1.302
12	60	2479.338	169239.6	352221.4	890187.8	760670.9	1.302
13	65	1467.603	83871.0	378387.8	1000734.1	786837.3	1.272
14	65	1467.603	83871.0	378387.8	1000734.1	786837.3	1.272
15	75	1404.956	79211.5	378387.8	1014324.3	786837.3	1.289

RUN = 43

LN	TS	S	VTC	PKW	AFM	AP	PGV	PGHV	PGTC	SS
1	0	0	885	128	6.2	55	7800	223.6	56	
2	4	1	885	128	6.1	55	7000	223.6	60	
3	9	2	885	132	6.0	55	8800	249.3	66	
4	15	3	880	132	6.0	55	9999	225.6	70	
5	23	3	900	132	6.0	55	9999	201.8	74	
6	32	4	910	134	6.0	55	9700	285.8	83	
7	35	0	815	134	6.0	50	9300	141.6	81	
8	43	5	925	134	6.0	50	3500	97.3	75	
9	50	3	830	132	6.1	50	2700	120.1	78	
10	61	6	940	130	6.0	50	9100	142.8	86	
11	67	7	950	130	6.0	50	8000	145.6	84	
12	70	0	860	128	6.0	50	7600	131.3	81	
13	80	8	980	128	6.1	50	2400	116.9	81	
14	80	0	880	0	6.1	50	2400	116.9	81	
15	93	0	980	0	6.1	50	2000	116.9	81	

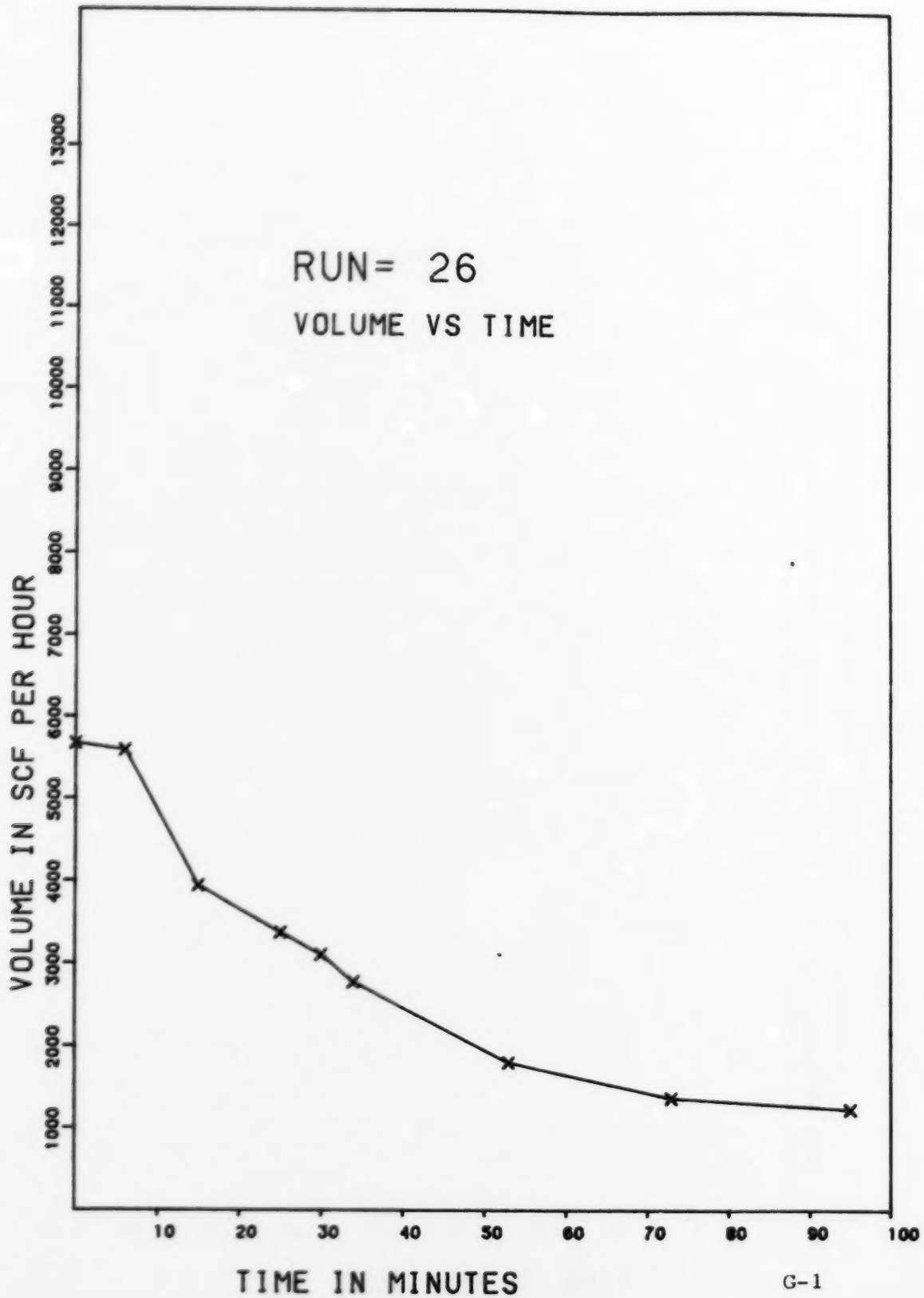
LINE	TIME	VC	MC	MPT	MC	MTI	EFF
1	0	7112.461	1590132.0	0.0	0.0	0.0	0.0
2	4	6306.305	1409900.0	29124.3	1000C1.1	607933.0	0.164
3	9	7787.609	1941884.0	66098.4	2396?0.4	644907.1	0.372
4	15	9745.480	1972630.0	111149.9	435365.9	689956.7	0.631
5	23	8644.668	1744407.0	171228.7	683168.3	750027.4	0.911
6	32	8174.156	1518921.0	239304.0	927917.9	818116.8	1.134
7	35	7881.355	1115763.0	262175.1	993784.9	840983.8	1.182
8	43	3017.241	293637.9	323153.9	1087744.0	901962.7	1.206
9	50	2307.692	277064.6	376112.3	1121036.0	954921.1	1.174
10	61	7604.453	1066067.0	458081.2	1245981.0	1036859.9	1.202
11	67	6722.688	979024.9	502450.2	1349245.0	1081258.0	1.248
12	70	6440.676	845338.7	524464.0	1394854.0	1103272.0	1.264
13	80	2033.898	237681.3	597274.6	1485105.0	1176083.0	1.263
14	80	2033.898	237681.3	597274.6	1485105.0	1176083.0	1.263
15	93	1694.915	198067.7	597274.6	1532311.0	1176083.0	1.303

APPENDIX G

GRAPHS

OF

REPRESENTATIVE RUNS


RUN= 26
VOLUME VS TIME
VOLUME IN SCF PER HOUR
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
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13000
10
20
30
40
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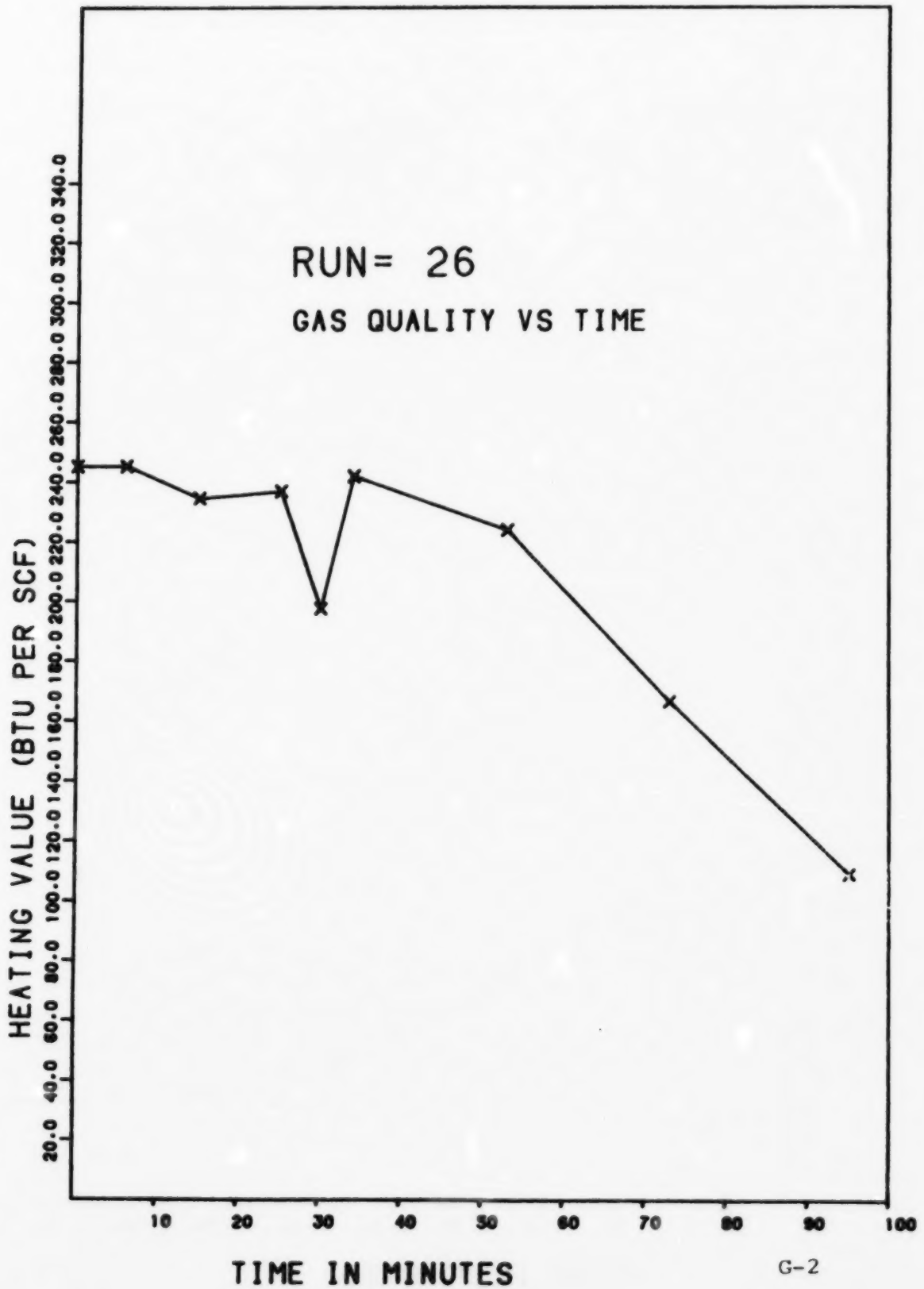
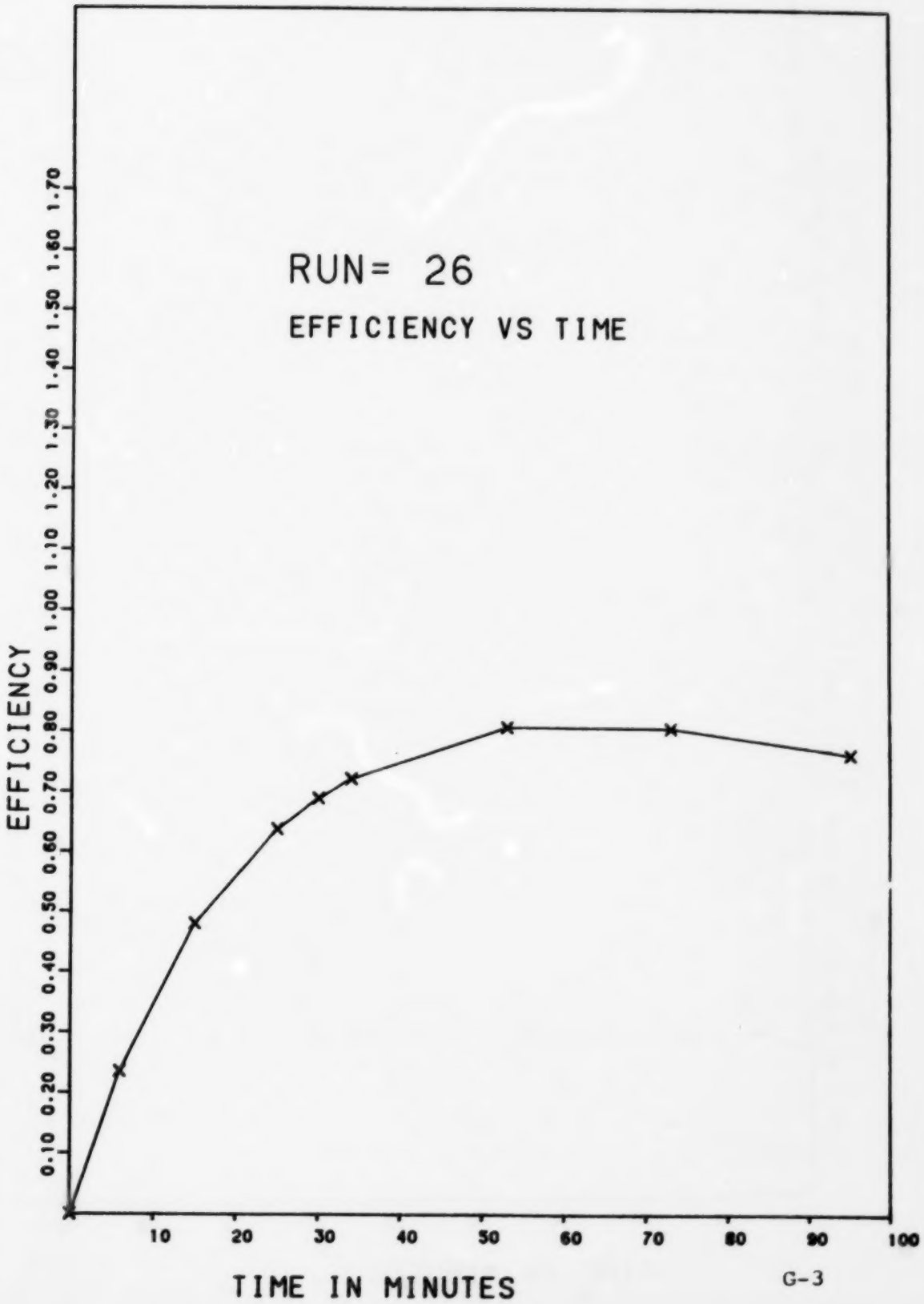
60
70
80
90
100
TIME IN MINUTES


RUN= 26
GAS QUALITY VS TIME
HEATING VALUE (BTU PER SCF)
20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0 220.0 240.0 260.0 280.0 300.0 320.0 340.0
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES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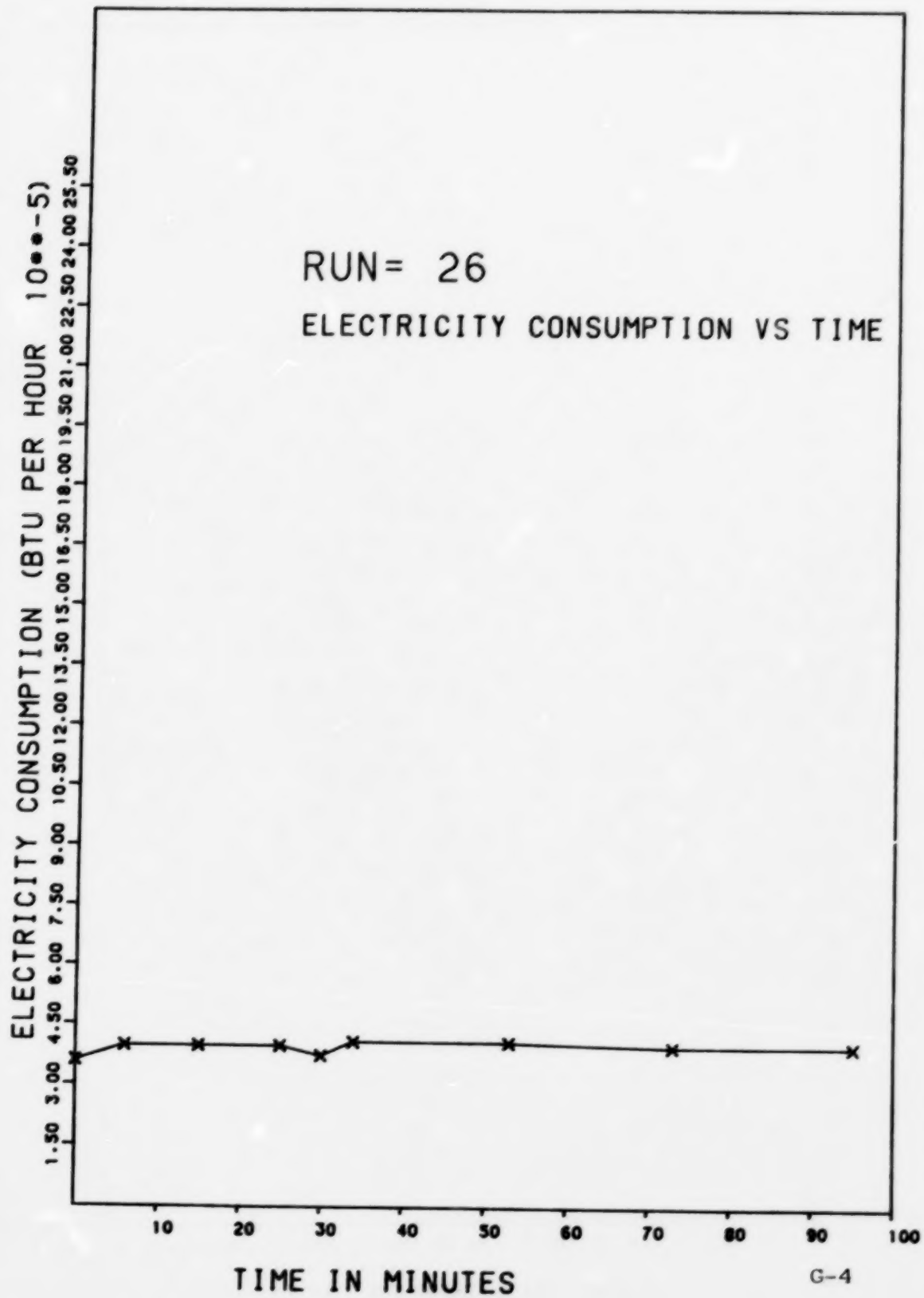
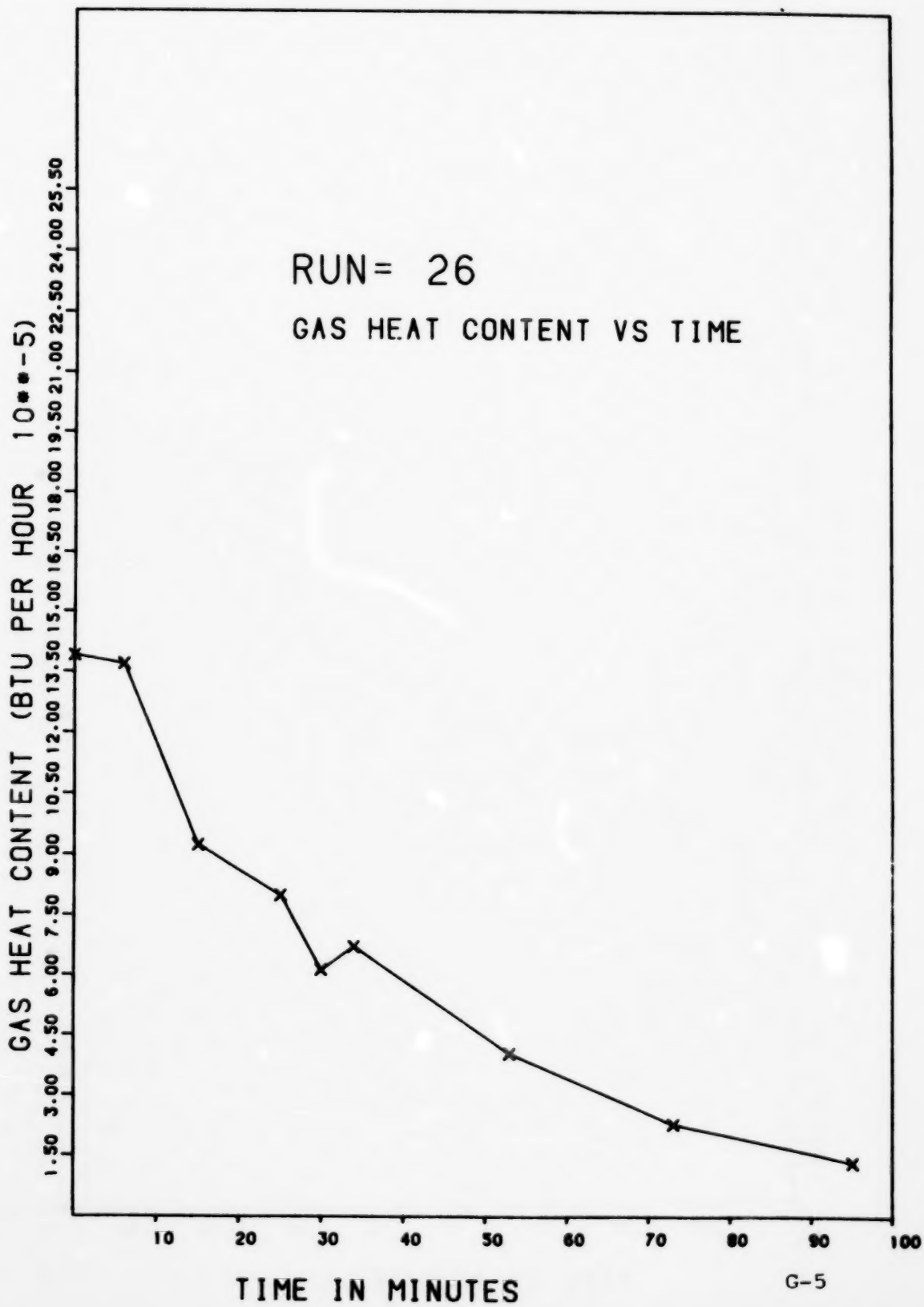
EFFICIENCY VS TIME
EFFICIENCY
0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 26
ELECTRICITY CONSUMPTION VS TIME
ELECTRICITY CONSUMPTION (BTU PER HOUR 10••-5)
1.50 3.00 4.50 6.00 7.50 9.00 10.50 12.00 13.50 15.00 16.50 18.00 19.50 21.00 22.50 24.00 25.50
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES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GAS HEAT CONTENT VS TIME
GAS HEAT CONTENT (BTU PER HOUR 10**-5)
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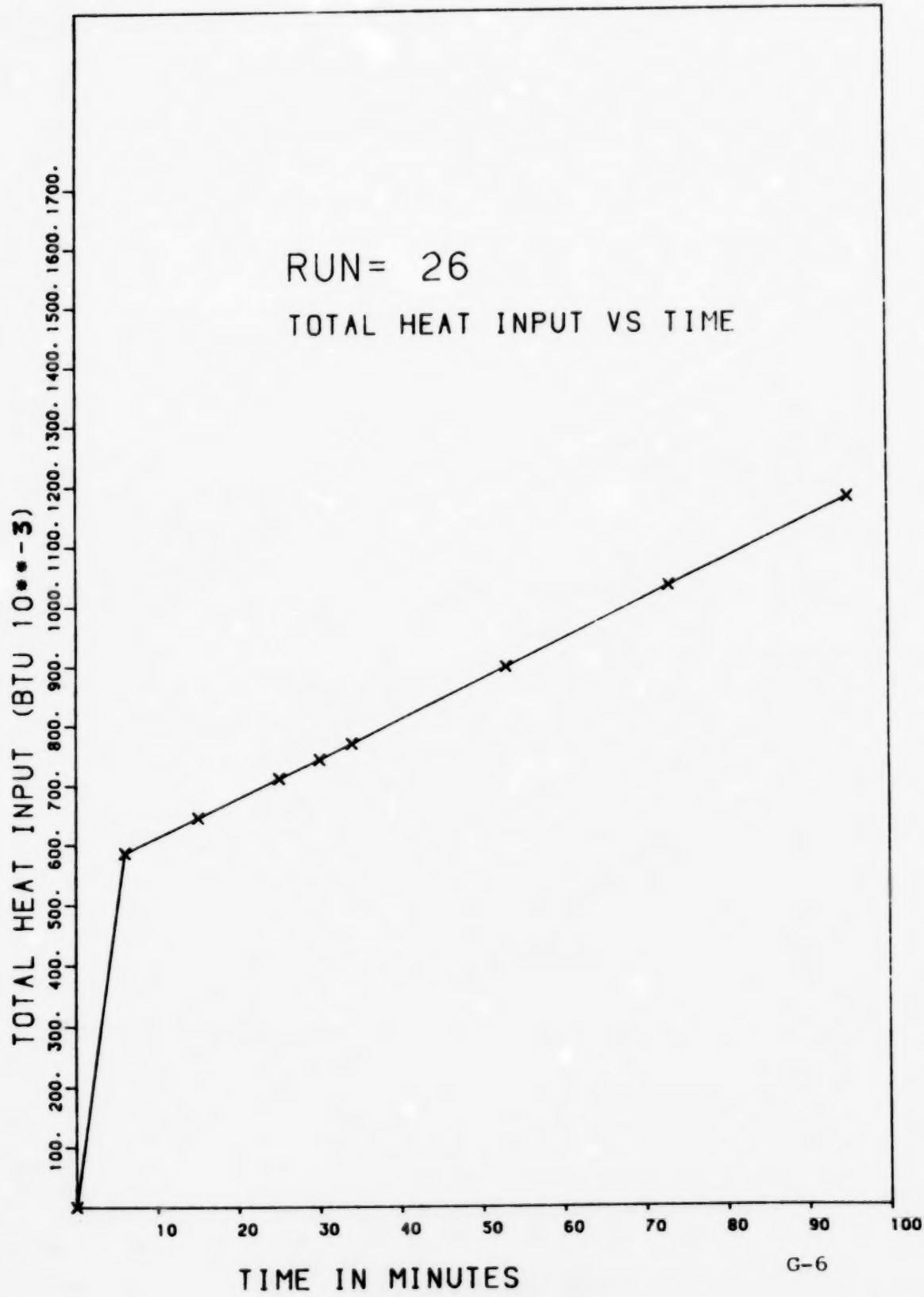
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES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TOTAL HEAT INPUT VS TIME
TOTAL HEAT INPUT (BTU 10**-3)
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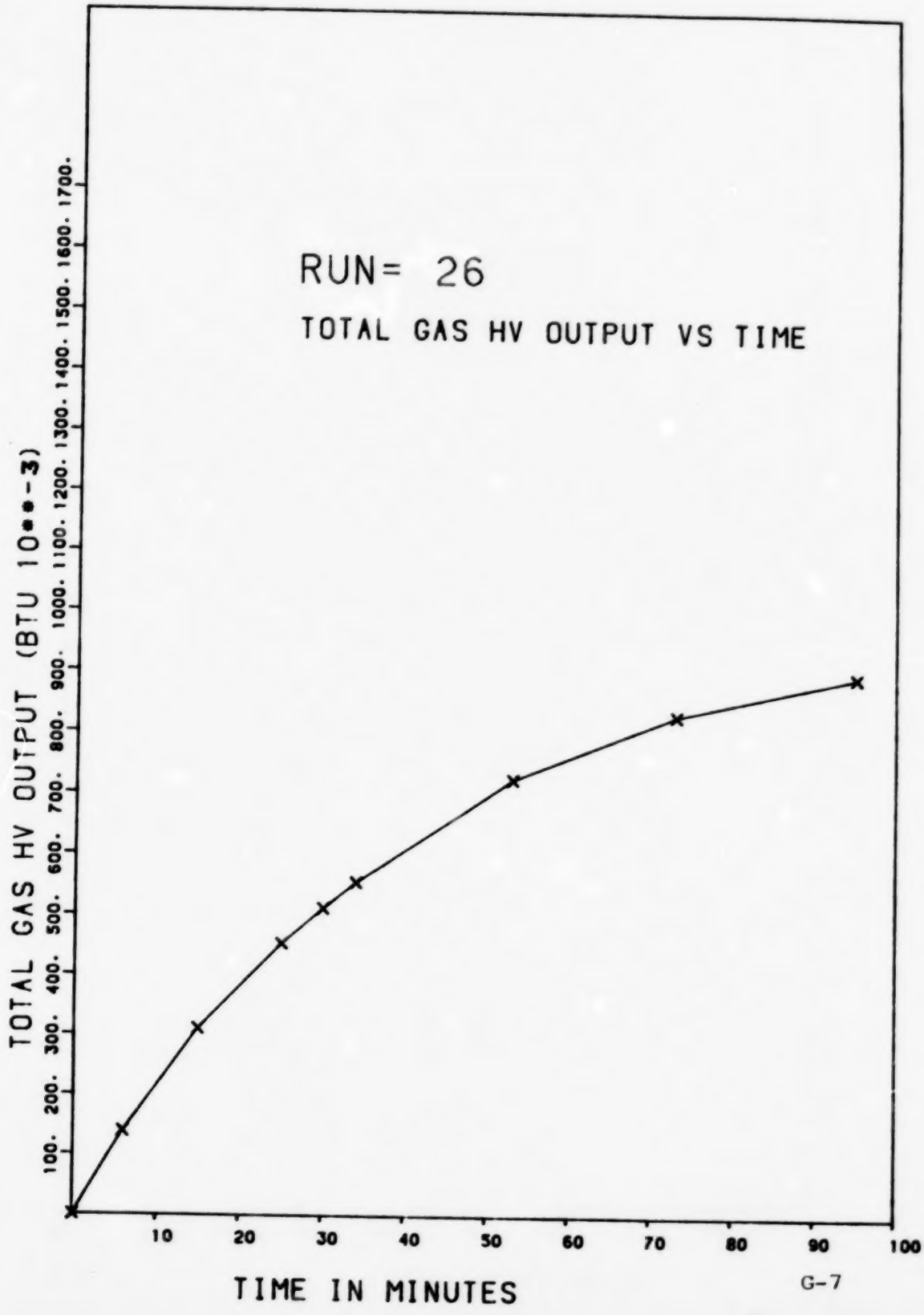
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES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TOTAL GAS HV OUTPUT VS TIME
TOTAL GAS HV OUTPUT (BTU 10**-3)
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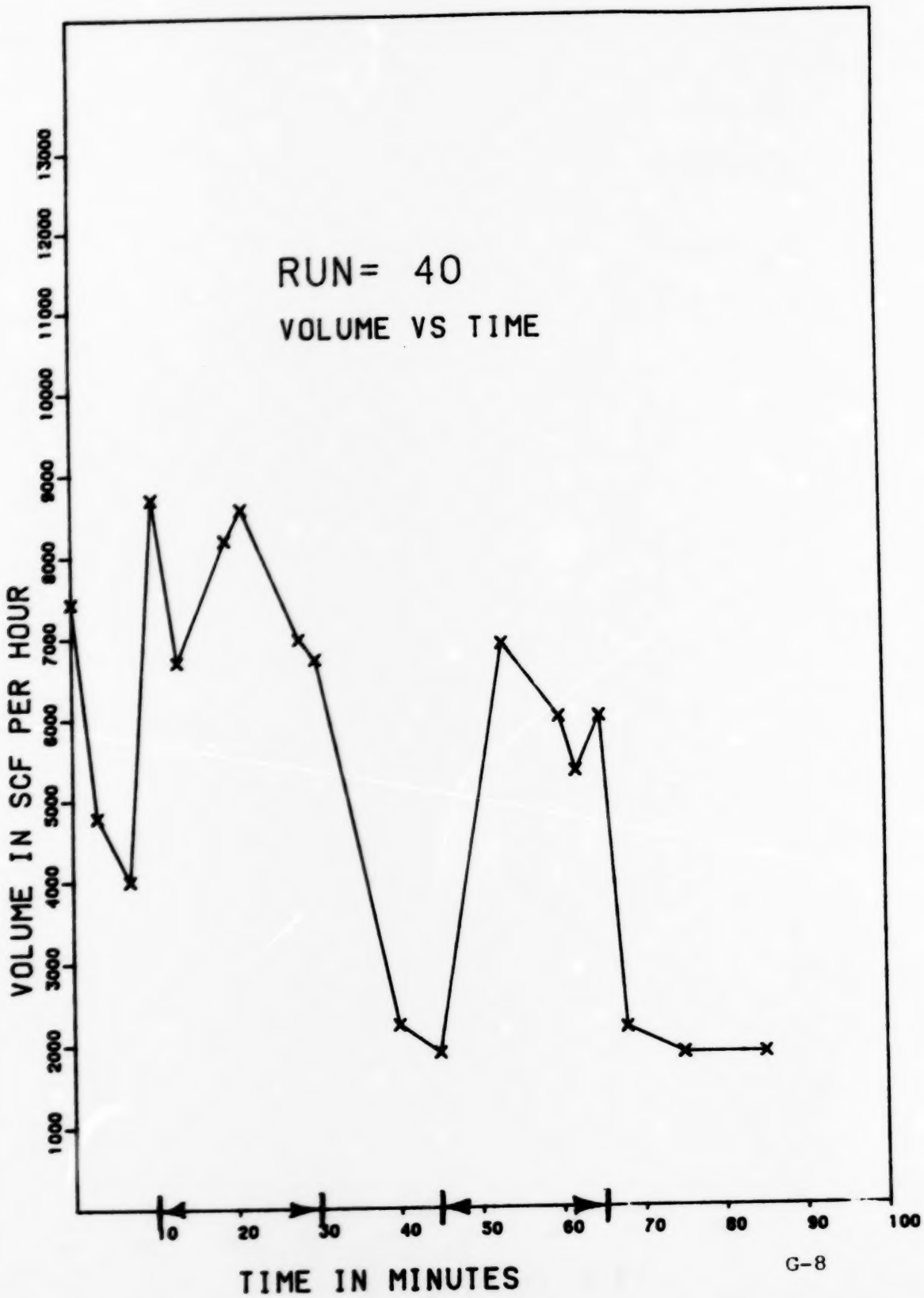
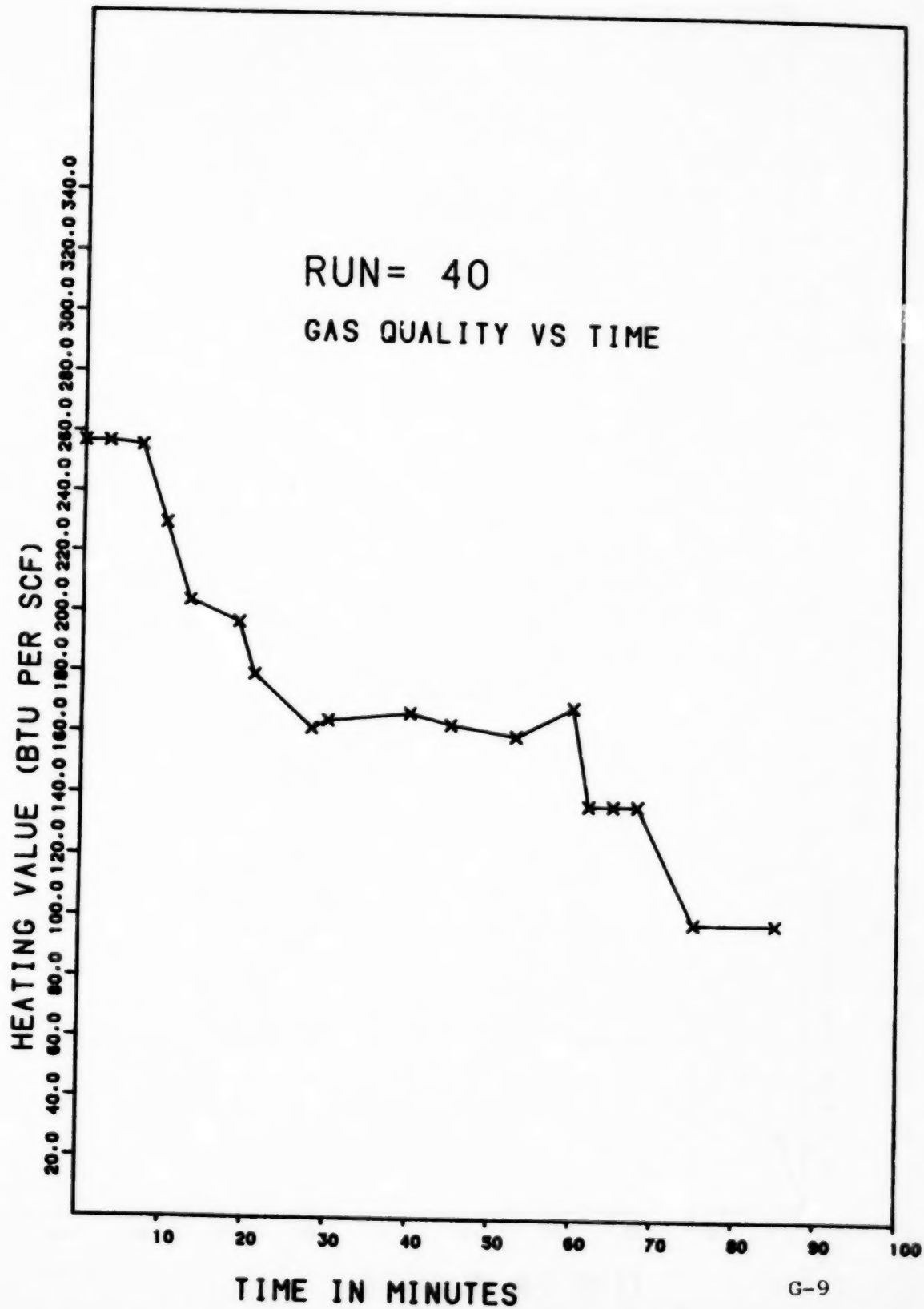
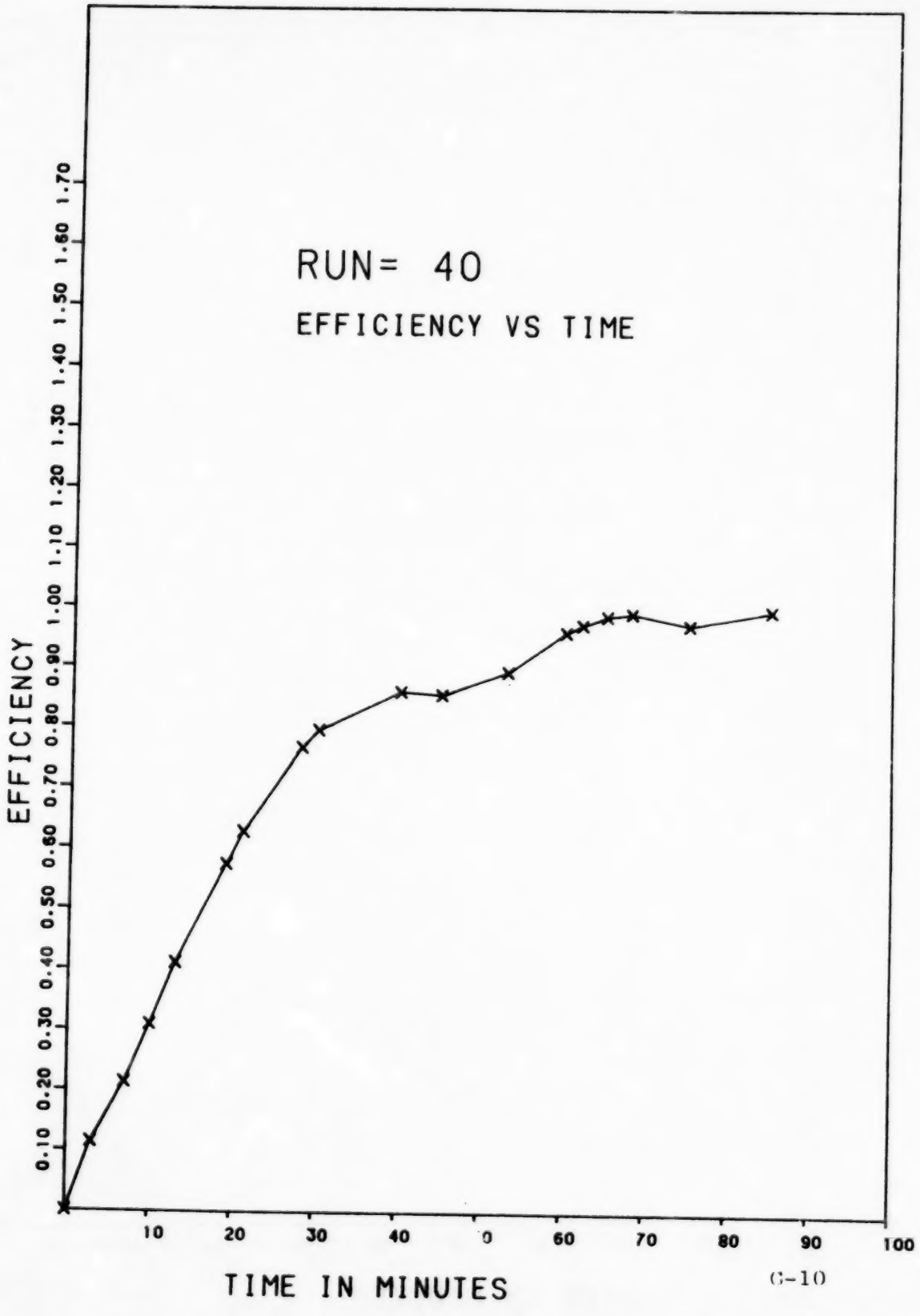
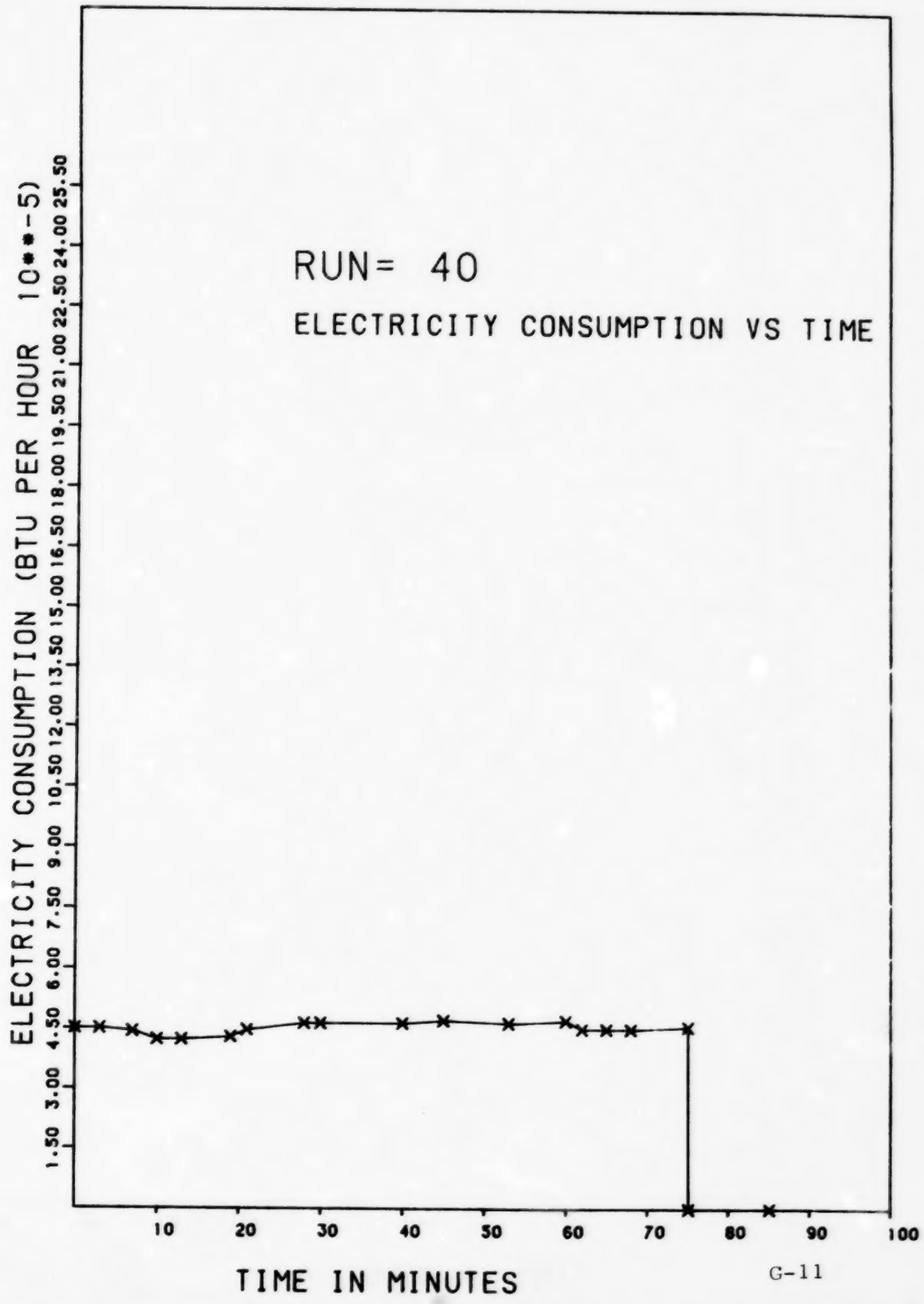
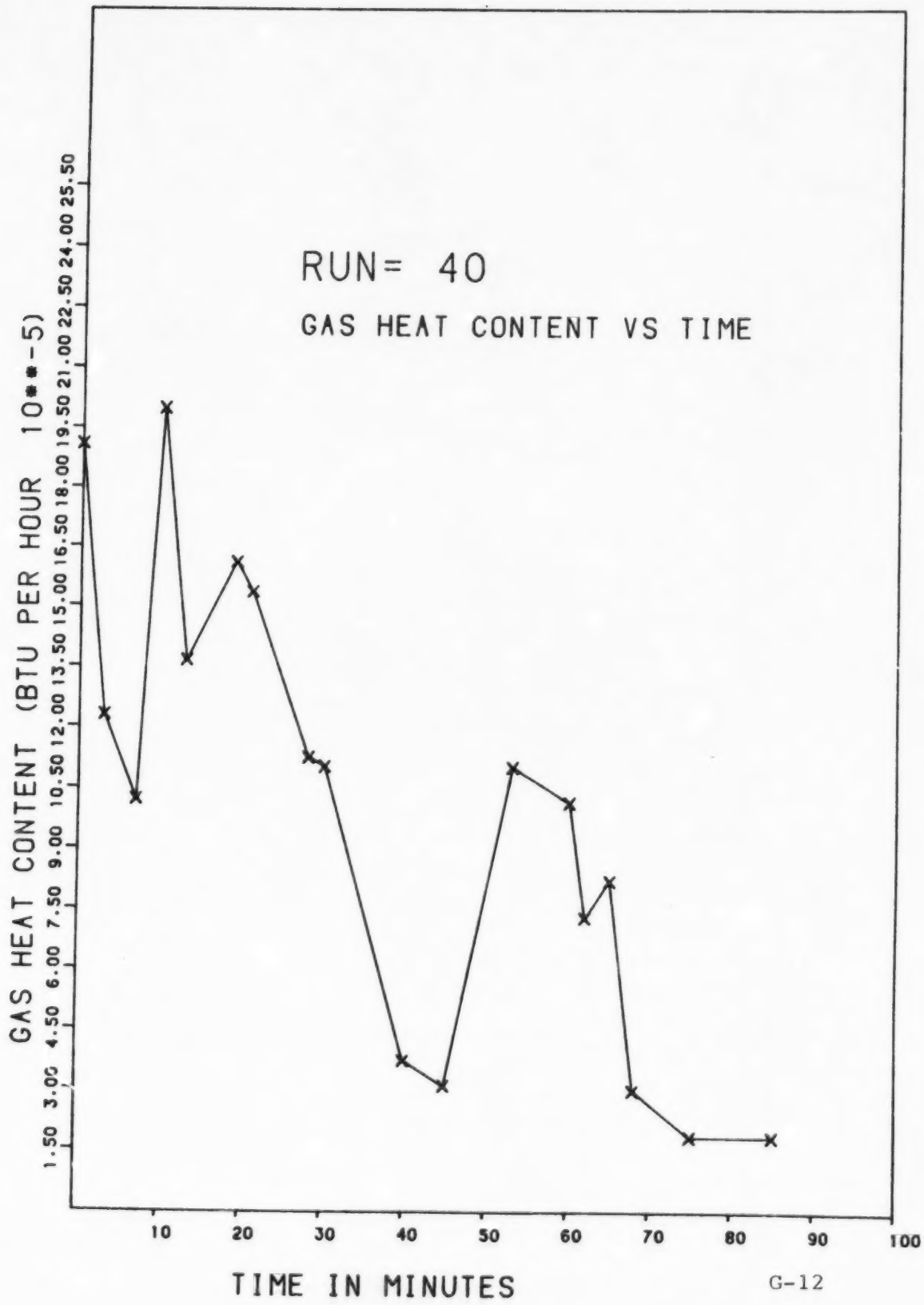
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 40
VOLUME VS TIME
VOLUME IN SCF PER HOUR
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
0
20
30
40
50
60
70
80
90
100
TIME IN MINUTES


RUN= 40
GAS QUALITY VS TIME
HEATING VALUE (BTU PER SCF)
20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0 220.0 240.0 260.0 280.0 300.0 320.0 340.0
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 40
EFFICIENCY VS TIME
EFFICIENCY
0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70
10 20 30 40 0 60 70 80 90 100
TIME IN MINUTES


RUN= 40
ELECTRICITY CONSUMPTION VS TIME
ELECTRICITY CONSUMPTION (BTU PER HOUR 10**-5)
1.50 3.00 4.50 6.00 7.50 9.00 10.50 12.00 13.50 15.00 16.50 18.00 19.50 21.00 22.50 24.00 25.50
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 40
GAS HEAT CONTENT VS TIME
GAS HEAT CONTENT (BTU PER HOUR 10**-5)
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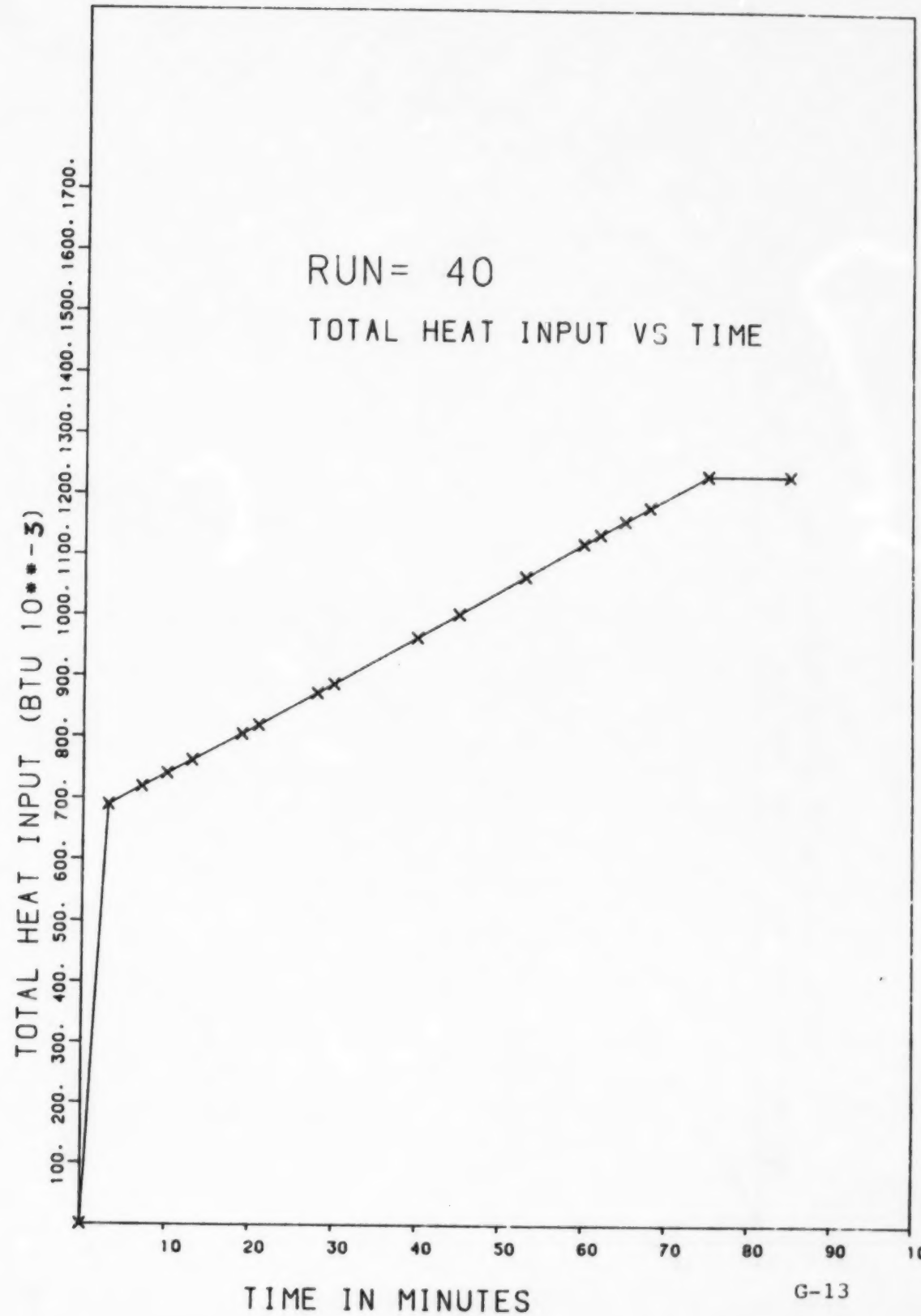
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 40
TOTAL HEAT INPUT VS TIME
TOTAL HEAT INPUT (BTU 10**-3)
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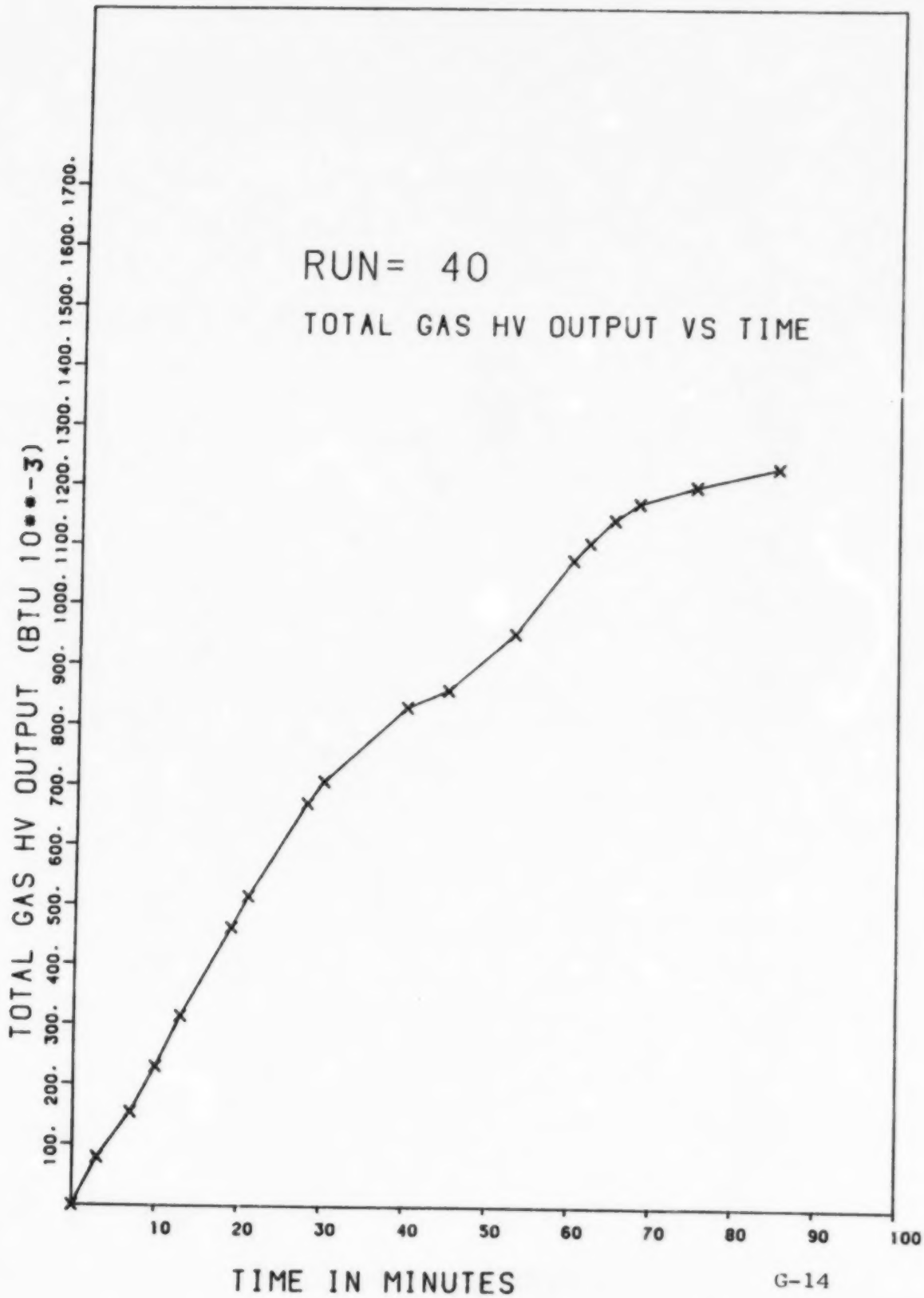
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 40
TOTAL GAS HV OUTPUT VS TIME
TOTAL GAS HV OUTPUT (BTU 10**-3)
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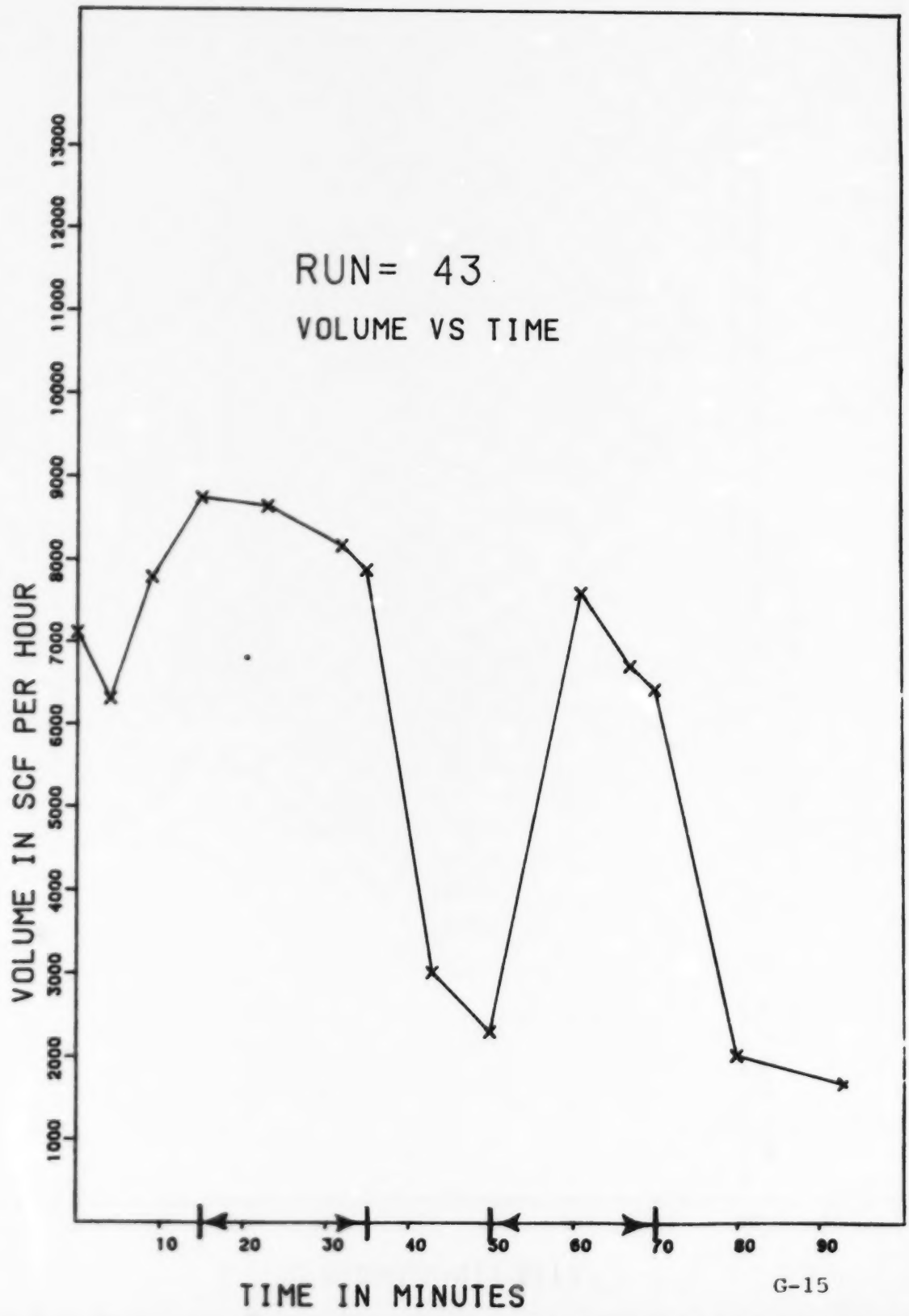
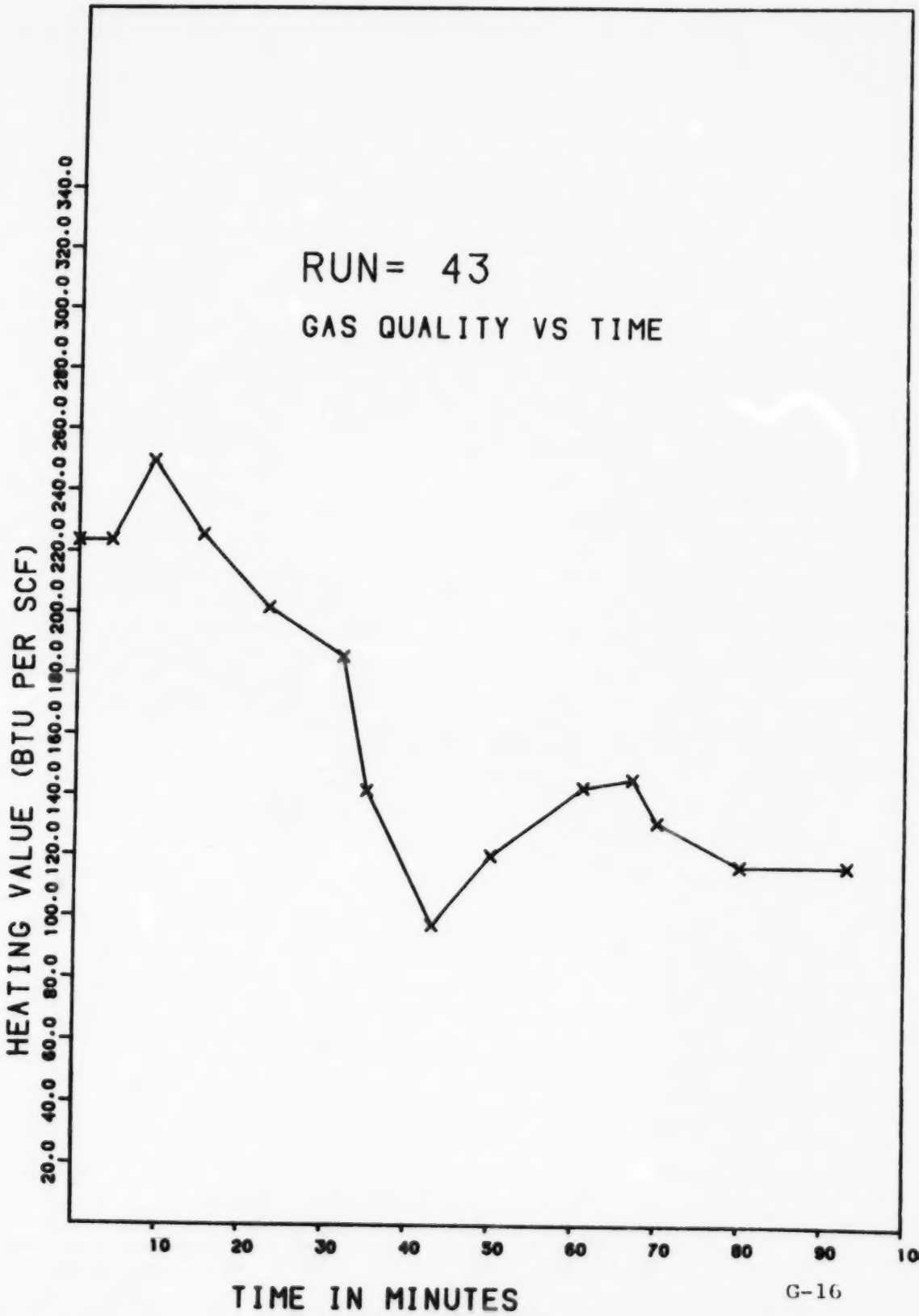
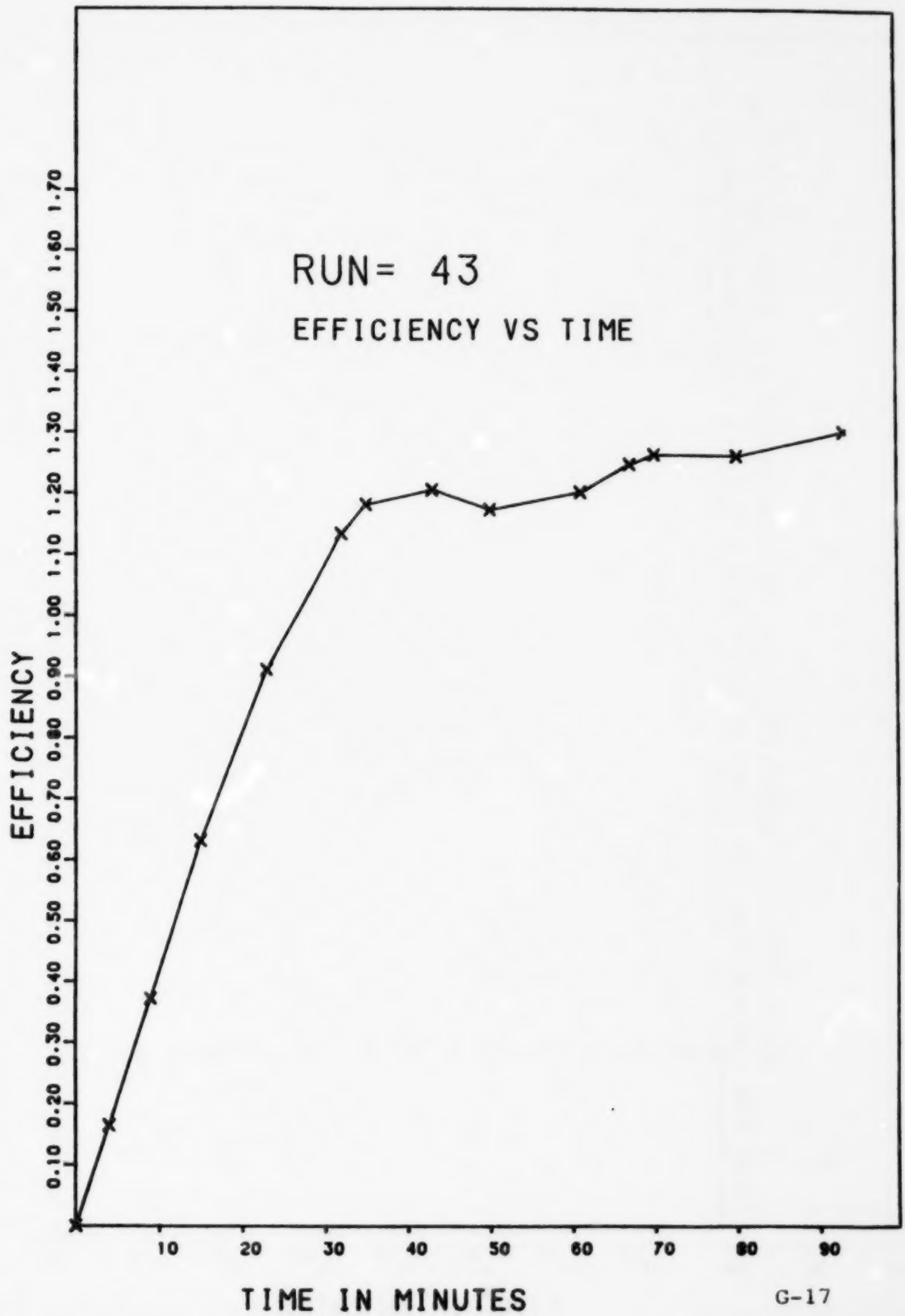
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 43
VOLUME VS TIME
VOLUME IN SCF PER HOUR
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
10
20
30
40
50
60
70
80
90
TIME IN MINUTES


RUN= 43
GAS QUALITY VS TIME
HEATING VALUE (BTU PER SCF)
20.0 40.0 60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0 220.0 240.0 260.0 280.0 300.0 320.0 340.0
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES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EFFICIENCY VS TIME
EFFICIENCY
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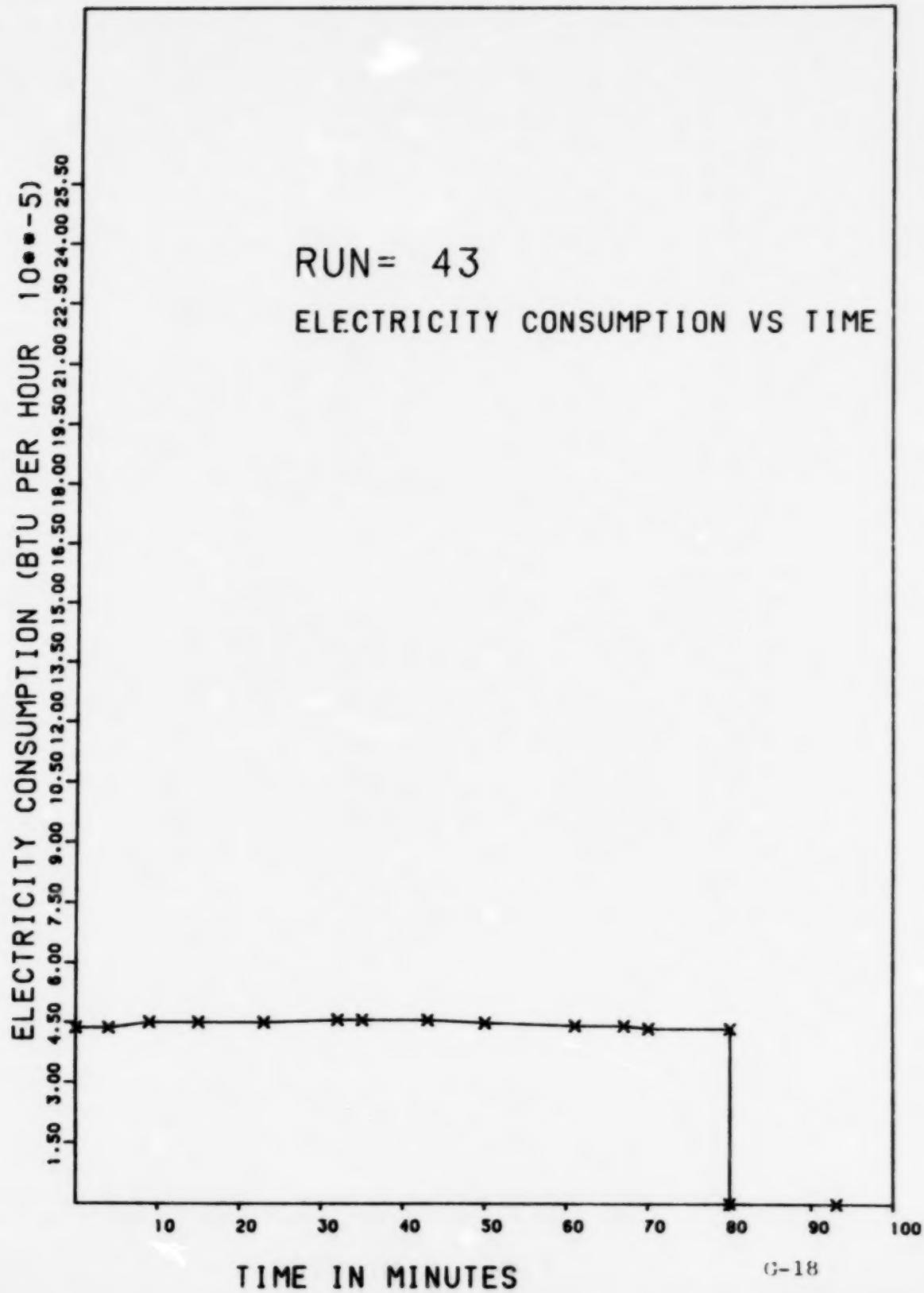
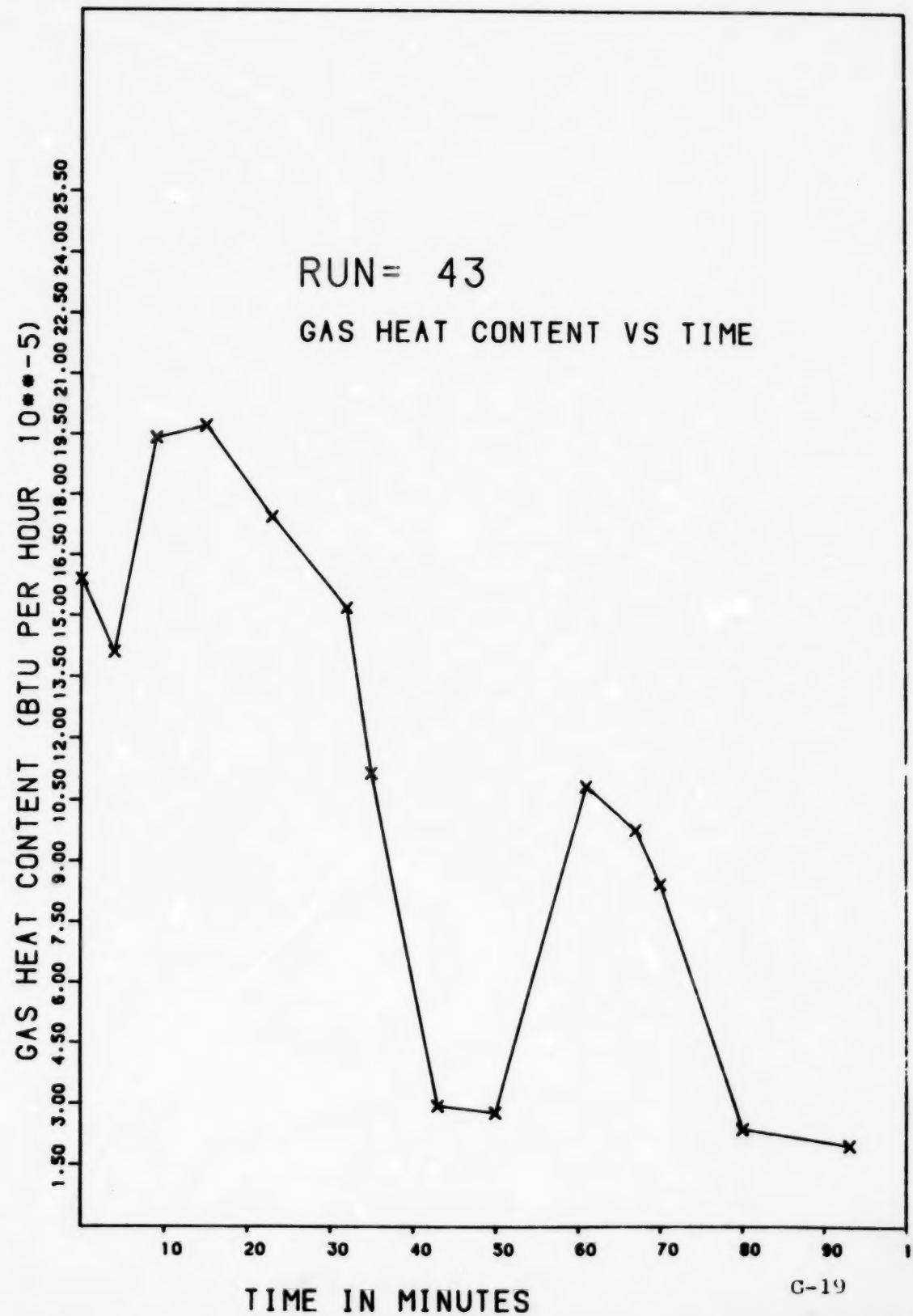
10 20 30 40 50 60 70 80 90
TIME IN MINUTES


RUN= 43
ELECTRICITY CONSUMPTION VS TIME
ELECTRICITY CONSUMPTION (BTU PER HOUR 10••-5)
1.50 3.00 4.50 6.00 7.50 9.00 10.50 12.00 13.50 15.00 16.50 18.00 19.50 21.00 22.50 24.00 25.50
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES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GAS HEAT CONTENT VS TIME
GAS HEAT CONTENT (BTU PER HOUR 10**-5)
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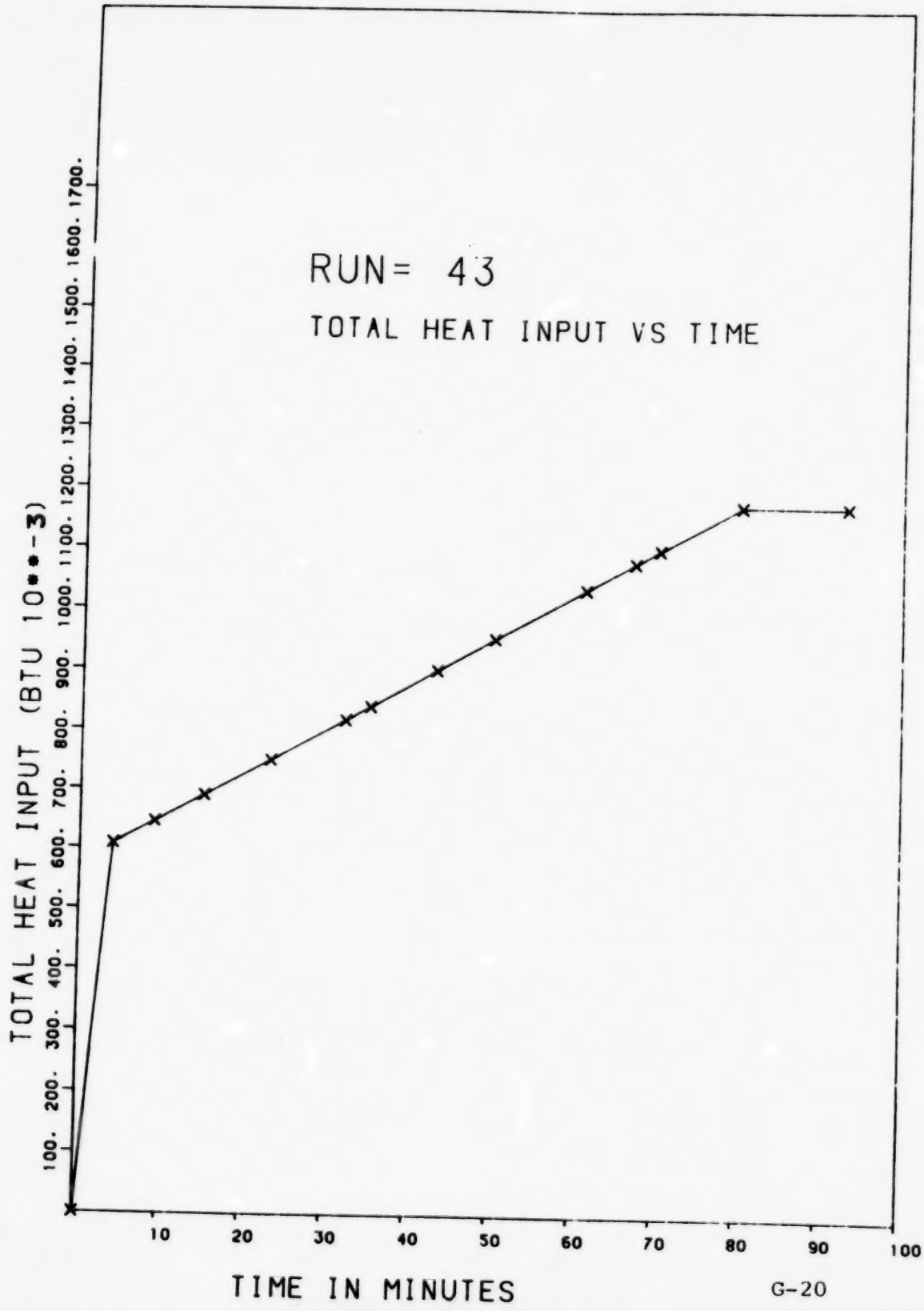
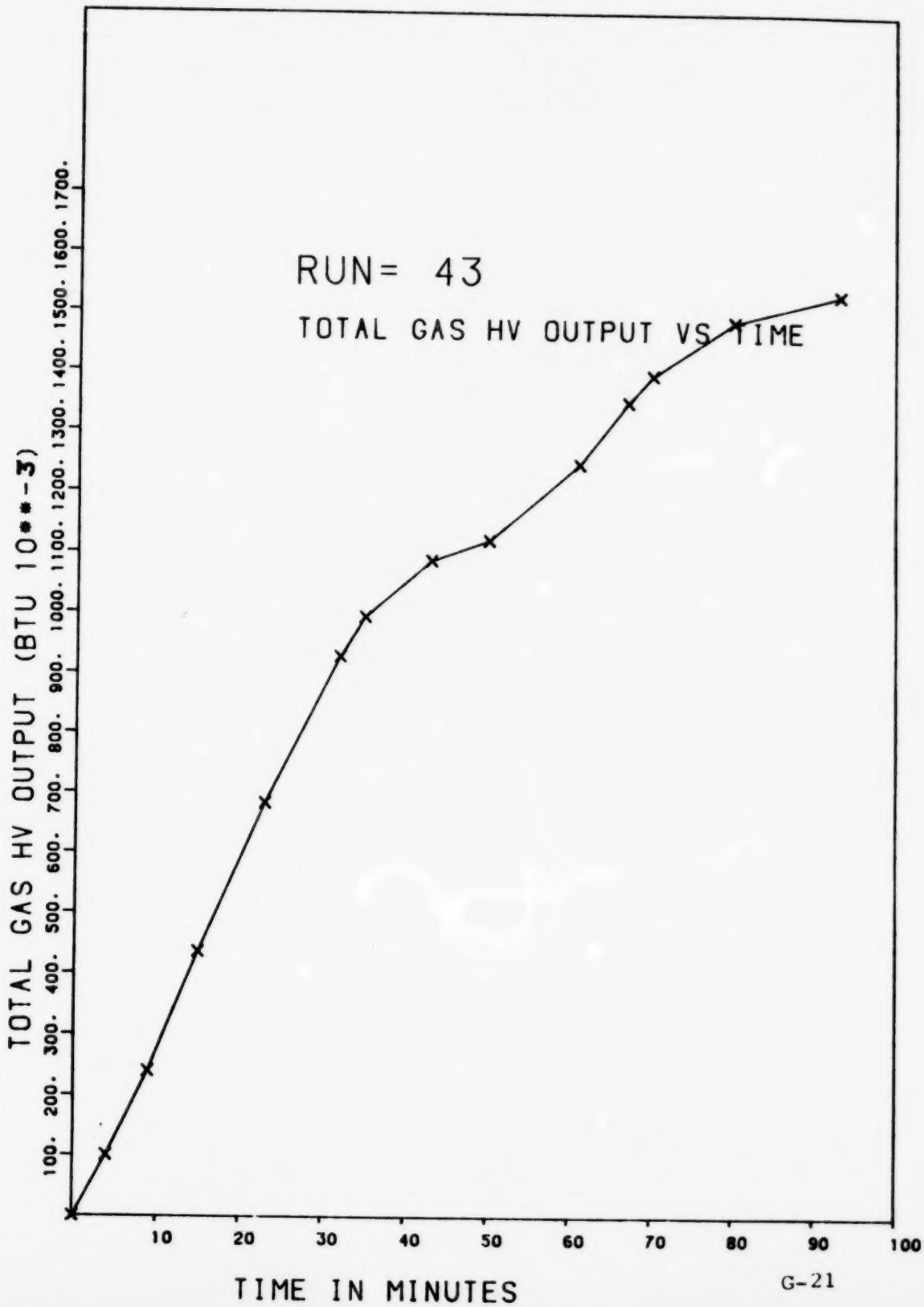
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 43
TOTAL HEAT INPUT VS TIME
TOTAL HEAT INPUT (BTU 10**-3)
100. 200. 300. 400. 500. 600. 700. 800. 900. 1000. 1100. 1200. 1300. 1400. 1500. 1600. 1700.
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES


RUN= 43
TOTAL GAS HV OUTPUT VS TIME
TOTAL GAS HV OUTPUT (BTU 10**-3)
100. 200. 300. 400. 500. 600. 700. 800. 900. 1000. 1100. 1200. 1300. 1400. 1500. 1600. 1700.
10 20 30 40 50 60 70 80 90 100
TIME IN MINUTES

APPENDIX H

THE PLASMA ARC TORCH

THE PLASMA ARC TORCH

1.0 General

A plasma arc torch is a device for producing an electrical "flame" called a plasma which is the hottest, sustainable flame known to man. The plasma generators used by RCL were developed in the US in conjunction with the US space program. Their initial purpose was to simulate the intense heat of reentry of the Mercury, Gemini and Apollo space capsules. Patents for the plasma arc torch and a number of its industrial applications are held by Plasma Energy Corporation (PEC) of Raleigh, North Carolina for which RCL has marketing rights.

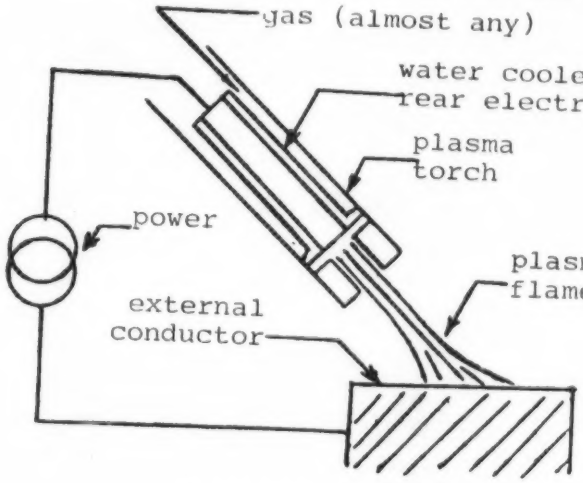
The plasma arc torch takes a very small quantity of any gas (argon, hydrogen, helium, nitrogen, oxygen, air, etc) and using electricity changes this gas into a plasma flame that can be made as hot as 50,000 degrees K. Unlike a combustion burner flame the plasma flame can be generated in the total absence of oxygen. Heat is therefore generated by electrical dissociation and ionization of the gas which can be extensively exploited in many heating applications.

Two types of plasma torch are available, a transferred arc torch (TAT) and a non-transferred arc torch (NTAT). The TAT strikes an arc between an electrode within the torch and an external conductor, whereas the NTAT strikes an arc between two electrodes within the torch (see diagram). The TAT is usually about 3% more efficient than the NTAT.

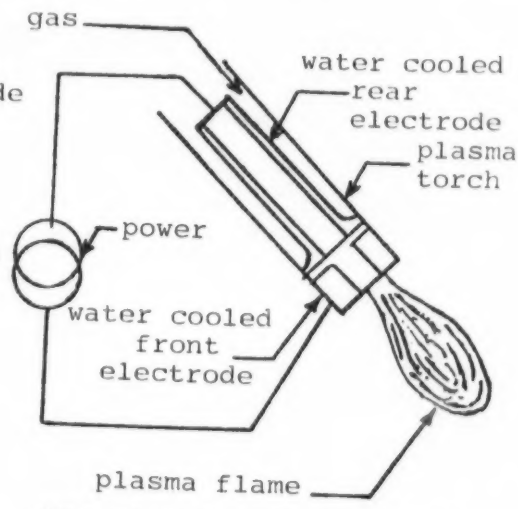
2.0 Plasma Torch Operation

To generate a plasma flame a gas must first be introduced to create a swirling motion inside the torch which keeps the plasma flame at the centre of the torch and away from the metal parts. An electrical discharge (arc) is established and

maintained between the two electrodes associated with the torch depending on its type. This arc is actually an ionization of the gas which then becomes a very efficient conductor of electricity. The swirling motion of the gas ensures the arc attachment point continuously changes position over time so as not to erode the electrodes.



Transferred Arc Torch



Non-Transferred Arc Torch

The electrical energy is converted very efficiently into heat energy by the plasma flame. This change is accomplished as follows:

1. If the gas is composed of single atoms such as argon, the electricity immediately ionizes the atoms to make up the plasma flame.

   Argon atoms + el energy produces Argon plasma + heat.

   This process is repeated many times to sustain the plasma flame; and

2. If the gas is composed of two atom molecules such as nitrogen (N2), two steps are involved.

   N2 + electrical energy produces N + N + heat, and

   N2 atom + elect energy produces N2 plasma + heat.

   In actuality, the process is not so well defined; both of the above steps take place simultaneously.

3.0 Plasma Torch Capabilities

- Materiels can easily be heated to high temperatures, the arc centreline temperature can be as high as 50,000 deg K and arc edge temperatures can be between 3000 and 8000 deg K.
- Electricity can be converted to high temperature heat with a conversion efficiency of 87-95%.
- Heat can be generated with many different gases making it possible to select a gas or gases which are compatible with the desired process.
- The torch can be operated continuously and stably for up to five days between electrode changes using air,and even longer using inert gases.
- The torch is reliable in providing high and continuously adjustable heat transfer rates without oxygen, combustion or pollution.
- The torch is designed and built with no moving parts for trouble free performance and easy maintenance.
- The torch is designed with versatility of operation, it can operate on AC or DC power and in the transferred or non-transferred arc mode.
- The torch is equipped with OFHC copper electrodes which are compatible with most gases.
- Plasma arc operation enables total gasification of any carbon bearing materiel.
- Plasma arc technology is less capital intense than other technologies.
- Materiel can be processed as received without drying or other preprocessing.
- System operating costs are less than for conventional systems.
- Biomass gasification yields are better than for other conventional technologies.
- The economic advantages of acid rain and other air pollution avoidance are not yet quantifiable but are anticipated to be substantial.

4.0 Plasma Heating System

4.1 General: The plasma arc torch has wide applicability in business and industry where a controlled source of high heat is required. The primary application of the torch is through an integrated system referred to as a Plasma Heating System (PHS) which is a self contained system including all components necessary for safe operation of the system within any environment and application. The PHS consists of:

- A plasma arc torch(es);
- A power supply;
- Water and gas sub-systems;
- A control panel; and
- Other auxiliaries.

4.2 Plasma Torch: The plasma arc torch is the primary heating element of the PHS.

4.3 Power Supply: The power supply converts the available hydro power to the power requirements of the torch. The major components of the power supply are a three phase transformer, a saturable core reactor per phase for current control, a full wave bridge rectifier using diodes or SCRs, and a specialized Low Energy Plasma (LEP) starter. Torches of 500KW or less require 600V, 3phase, 60cps power whereas higher power torches, up to 4.5MW, require 1000V.

4.4 Control Panel: The control panel is the brain of the PHS with respect to operation and control. It integrates all of the sub-systems for safe operation and monitoring of the plasma torch. Relay logic or a microprocessor is used to interlock the utilities (water, gas, power) in order to prevent damage to components and injury to personnel. The control panel has meters, gauges, switches, indicater lights, meter relays, timers, and other components for monitoring the performance of the plasma torch and the status of the other sub-systems.

4.5 Water and Air Sub-Systems: The plasma torch is water cooled through a closed loop water system. No special PH adjustment, deionization, decalcification, etc are required. Smaller torches require approximately 15-50 GPM whereas larger torches require approximately 80-100 GPM. The gas used for the plasma is generally air which can be provided by a standard air compressor system. No special air filters or dehumidification are required. Smaller torches require approximately 5-15 scfm whereas larger torches require approximately 50-100 scfm.

4.6 Other Auxiliaries: These include the power cables, water piping and hoses, gas piping and hoses, control wires, instrumentation wires, etc for complete integration and operation of the sub-systems.

4.7 Applications: The PHS can be used as the heater in a number of different industrial process applications. The plasma torch can be installed inside a furnace chamber or any other high heat sustaining chamber for efficient utilization of its heat. The plasma torch flame is compatible with almost any process that requires heat. The utilization of a TAT or a NTAT in the PHS provides maximum versatility of operations throughout different processes. The main processes within which the PHS has proven applicability are:

- Gasification of any carbon bearing materiel;
- Manufacturing of iron, steel, glass, cement, etc;
- Ozone production;
- Smelting/Melting/Recovery/Reclamation;
- Annealing/Cladding;
- Annihilation/Cutting/Reduction;
- Crystal Growing; and
- Heating/Preheating/Drying/Ignition.

POOR

QUALITY

ORIGINAL